The WELDING JOURNAL

JUNE 1954

OFFICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY

BRAND NEW!

Our new hard-facing manual has separate sections showing typical hard-surfacing applications in SEVEN basic industries. Every procedure job proved.

Tells which alloy to use and how to apply it.

Describes complete line of Victor alloys for gas or electric manual and automatic welding.

Printed on heavy paper with durable covers, for field use.

GET YOUR FREE COPY NOW

Mail Coupon Today

Victor Equipment Company,
Alloy Rod & Metal Division
11440 So. Alameda St., Los Angeles 59, Calif.

Gentlemen: Send my free VICTOR hard-surfacing manual. I need sections covering:

- ☐ *Brick and clay*
- ☐ *Cement*
- ☐ *Coal mining*
- ☐ *Dredging*
- ☐ *Earth moving*
- ☐ *Metal mining*
- ☐ *Rock products*

Name_____

Position_____

Company_____

Address_____

City_____ State_____

TYPICAL MANUAL PAGE

Illustrates the part (1) . . . the alloy Victor recommends (2) . . . and how to apply it (3)

Profitable dealerships open; inquire now!

VICTOR
for welding

12-H

VICTOR EQUIPMENT COMPANY

ALLOY ROD AND METAL DIVISION
11440 So. Alameda St. • Los Angeles 59

Mfrs. of welding & cutting equipment; hardfacing rods; blasting nozzles.

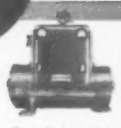
Try...Compare...the New HOBART Arc Welders

300 amp. electric portable

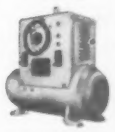
. . . and you'll see why you get more actual benefits in dollar savings and INCREASED PROFITS! HOBART'S outstanding design and special features bring **higher performance, faster welding and lower cost operation** in a compact and easy to move unit.

200 amp. air cooled gas drive

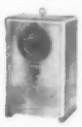
For Plant Production and Maintenance



For Automatic Welding



Bantam Champ



AC Transformer Welders

ELECTRIC MOTOR DRIVEN. Production, maintenance and general shop welding can be done faster and better than you ever thought possible. Made for light work or heavy in 200, 300, 400 and 600 ampere sizes—either stationary or portable.

If you are not using Hobart, you'll want to investigate these money-saving, profit-making welders. An investigation costs you nothing. Find out how you can get better, lower cost welding. Just mail coupon for complete details.

300 amp. Gas Engine Drive

For Construction Building and Repair

AC Welder AC Power Combination

250 Ampere "Pipeliner"

GAS ENGINE DRIVEN Hobart offers a wide range of models and sizes to meet every welding requirement . . . available with air or water engines.

Now you can have AC welding and AC power for jobs away from power lines or as emergency power for electric lights . . . to operate power tools, motors, etc. Use coupon for complete information without obligation.

HOBART Electrodes, too are best by Comparison

Try them. Comparison will prove you can get more top quality welding per day. Hobart electrodes are made for every application of A.C. or D.C. welding. Tell us the type work you do and we'll send samples for you to try!

HOBART TROY OHIO WELDERS

made by HOBART, one of the world's largest builders of arc welders and welding equipment.

Hobart Brothers Co., Troy, Ohio, Phone 21223

☐ FREE Weldor's Vest Pocket Guide . . . a practical guide to better Welding techniques.

HOBART BROTHERS COMPANY, BOX WJ-64, TROY, OHIO

Send information on the items checked below.

_____amp. Capacity ☐ Portable ☐ Stationary

☐ Electric Motor Driven Welders ☐ Gas Engine Driven Welders ☐ Free Electrode Samples—state type work_____

☐ Other _____

NAME_____POSITION_____

FIRM_____

ADDRESS_____

HOBART WELDERS, ELECTRODES

THIS NEW ELECTRODE CATALOG WILL MAKE YOUR JOB EASIER!

The new Murex catalog—just off the press—makes it easy to select exactly the right electrode for any arc welding application. It tells where to use and how to use each of 20 mild steel and low alloy electrode types. It contains full information, including physicals, chemical analyses, code and specification qualifications and standard sizes on each of these electrodes.

You will find frequent use, too, for the helpful engineering data section containing procedures for estimating welding costs, hardness conversion tables, lists of SAE steels and other reference material.

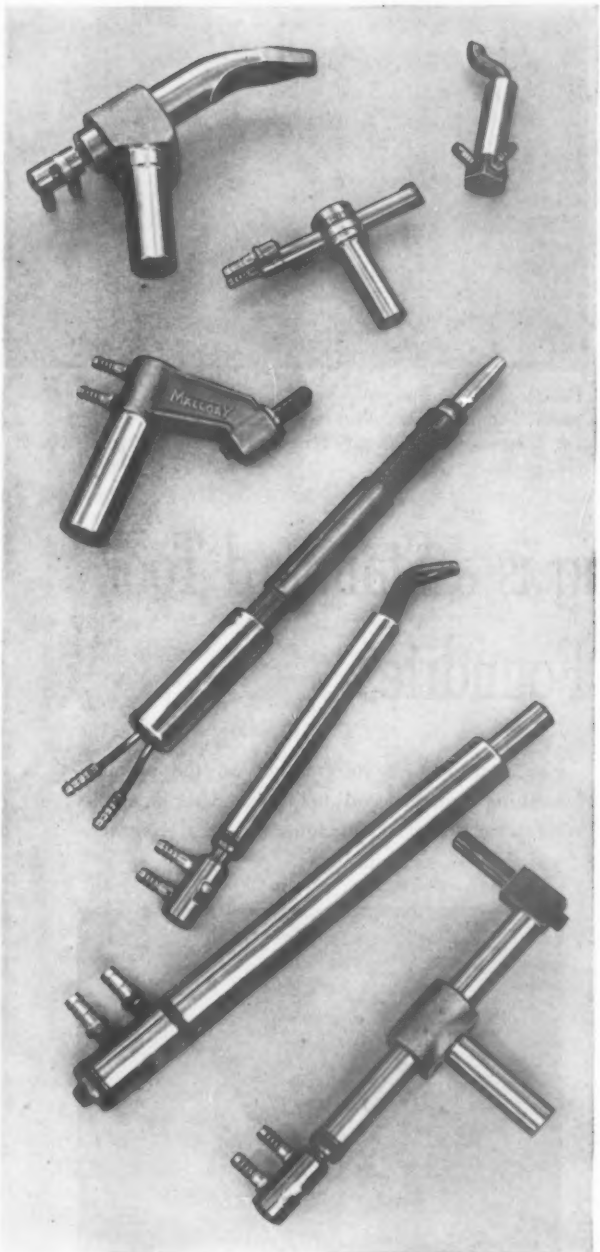
Make sure you get your copy by writing on your company letterhead today. Or, ask your M & T representative or distributor to reserve one for you now.

METAL & THERMIT CORPORATION

100 East 42nd Street • New York 17, N. Y.

Murex Electrodes • Arc Welders • Accessories

No Job is a "Special"...



with Mallory Resistance Welding Holders and Electrodes

Welding pressures from under 100 pounds to over 6000 pounds can be handled by standard Mallory holders and electrodes . . . available from stock.

In addition, holders and electrodes are available in such a wide variety of shapes and designs that standard units can be combined in an almost infinite number of combinations. Practically any resistance welding job can be done without the cost or delay of special designs.

The Mallory line is the result of over 25 years of experience in the development of special alloys and a complete range of designs. Write us, or ask your distributor, for the new Mallory Catalog. See for yourself the complete line of holders, electrodes, rods & bars, dies, castings, forgings, and accessories that are on the shelf for immediate delivery.

Expect more...
Get more from
MALLORY

In Canada, made and sold by Johnson Matthey and Mallory Ltd.
110 Industry Street, Toronto 15, Ontario

Serving industry with These Products:
Electromechanical—Resistors • Switches • Television Tuners • Vibrators
Electrochemical—Capacitors • Rectifiers • Mercury Batteries
Metallurgical—Contacts • Special Metals and Ceramics • Welding Materials

P. R. MALLORY & CO. Inc.
MALLORY
P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

For information on titanium developments, contact Mallory-Sharon Titanium Corp., Niles, Ohio

Powder-washing blowpipes have replaced swing grinders and chippers in removing defects and riser pads from railroad diesel trucks. Work is done faster and more efficiently—preheating is rarely necessary.

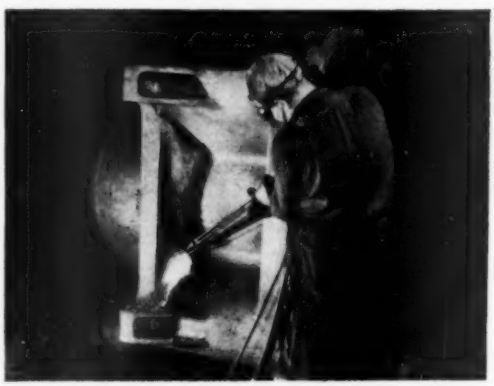
Powder-washing blowpipes remove riser pads in locations virtually impossible for other methods. Risers between flanges of this valve body have already been washed away—note the smooth clean finish.

Why Powder-Washing is a Standard Tool in Modern Foundries

Powder-washing is the fastest, most efficient method for gouging and removing fins, pads, and stubs from casting surfaces and hard-to-reach places.

* Powder-washing is faster than grinding or chipping, and finished surfaces are clean and smooth.
* Powder-washing tools are quiet, easy to operate, and less fatiguing than chipping tools and grinders.
* In powder-washing, metal powder is added to the washing flame. This raises its temperature, and provides greater speed and control in cleaning sand and metal from castings. This process is effectively used to gouge or wash iron, steel, bronze, and some of the more complex oxidation resistant alloys.

Your local LINDE representative will be glad to give you detailed information on the powder-washing process, and help you determine the setup to best serve your foundry needs. Save time and money—call him today.



LINDE AIR PRODUCTS COMPANY
A Division of Union Carbide and Carbon Corporation
30 East 42nd Street UCC New York 17, N. Y.
Offices in Other Principal Cities
In Canada: DOMINION OXYGEN COMPANY
Division of Union Carbide Canada Limited, Toronto

Linde
TRADE-MARK

"Linde" is a registered trade-mark of Union Carbide and Carbon Corporation.

Published for the advancement of the science and art of welding by the AMERICAN WELDING SOCIETY

Editor
W. SPRARAGEN
Assistant Editor
B. E. ROSSI

The WELDING JOURNAL

Volume 33 **JUNE 1954** *Number 6*

TECHNICAL PAPERS, ITEMS AND REPORTS

Effect of Power Supply Characteristics on Sigma Welding, by W. H. Helmbrecht and R. L. Hackman 531
Insert-Gas-Shielded Titanium Brazing, by Harlan L. Meredith 537
New Results in Tool and Die Welding, by Robert Groman 543
High-Speed Motion Picture Photography Applied to Resistance Welding, by I. S. Goodman 548
Current Welding Literature 552
Process Adjustment in Inert-Gas-Shielded Arc Welding, by Eugene B. LaVelle 553
Current Rectification and High Frequency Interference in Inert Gas Welding, by J. G. Murray 561

EDITORIAL PREVIEWS

New Kearny Generating Station—Public Service Electric and Gas Co. 564
New Automatic Welder Used in Laying Longest Aluminum Pipe Line 566
Tunnel Shield Welded 568
Mobile Arc Welders Go Directly to Jobs 569

PRACTICAL WELDER AND DESIGNER

2500-MPH Wind Tunnel Provides Stud Welding's "Biggest" Job 571
The Adaptation of the Semiautomatic Welder to Magnetic Flux, by R. A. Hand 573
How to Build a Television Stand, by Guthrie B. Stone 574
New Spot-Welding Method Reapplies Stainless Steel Car Sidings 575
Welding Giant Sheaves 576
Heavy Wall Pipe Welded Direct to Thin Wall Pipe 577

SOCIETY AND RELATED EVENTS

Society News 579
News of the Industry 584
Personnel 593
Employment Service Bulletin 595
New Literature 598
New Products 602
List of New Members 615
Section News and Events 617
Abstracts of Current Welding Patents. 623
Index to Advertisers 626

WELDING RESEARCH SUPPLEMENT

Nucleation and Growth of Graphite in Steel, by Floyd Brown 257-s
Exploratory Tests of the Air-Carbon Arc Cutting Process, by A. R. Hard 261-s
Fatigue as a Factor in Pressure Vessel Design, by T. J. Dolan 265-s
Fatigue Tests of Steel Specimens Prepared for Metallizing, by R. C. Miller, Jr. and A. W. Brunot 275-s
Research of Welding Arc, by M. Ozawa and T. Morita 280-s
Fatigue Strength of Butt Welds Made with Different Electrodes, by G. Becker and R. Rieger 284-s
Penetration Factors in Metallic Arc Welding, by Roger C. Waugh and Otto P. Eberlein 285-s
Oxy-Acetylene Stress Relieving of Pressure Vessels, by Hans Kunz 288-s
The Fatigue Factor in Welded Design, by A. Erker 295-s

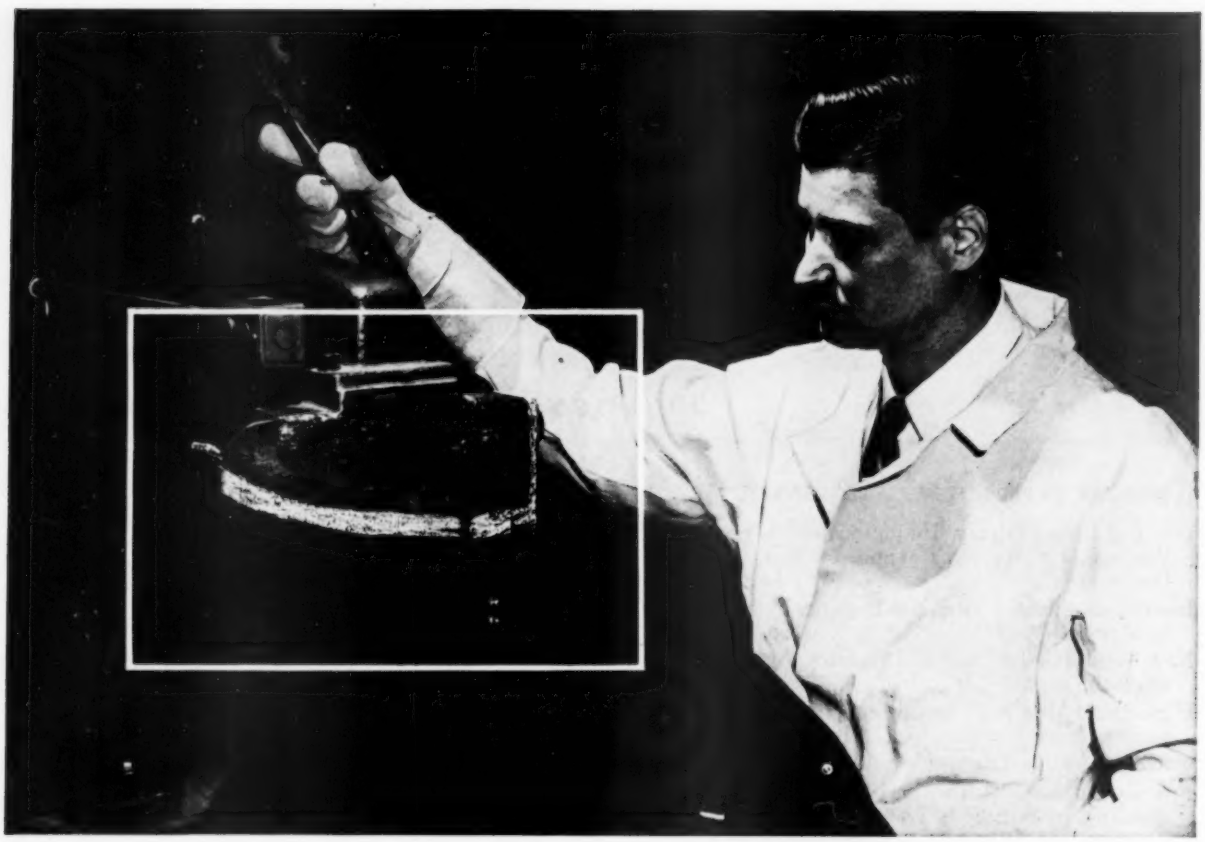
OFFICERS OF THE SOCIETY

F. L. PLUMMER	*President*
J. H. HUMBERSTONE	*1st Vice-President*
J. J. CHYLE	*2nd Vice-President*
R. S. DONALD	*Treasurer*
J. G. MAGRATH	*Secretary*
F. J. MOONEY	*Asst. Secretary*
S. A. GREENBERG	*Technical Secretary*

DISTRICT DIRECTORS

1—New York and New England	CLARENCE E. JACKSON
2—Mid-Eastern	D. B. HOWARD
3—Southern	ALFRED E. PEARSON
4—Central	J. H. BLANKENBUEHLER
5—Mid-Western	JEROME WELCH
6—Mid-Southern	J. E. DATO
7—Western	CLARENCE M. STYER

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices 33 West 39th St., New York 18, N. Y. Subscriptions $6.00 per year in the United States and possessions; foreign countries $7.50. Single copies, nonmembers $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton Pa., under the act of March 3, 1879. Copyright 1954, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided proper credit is given.



Bob Riegle, welding specialist for Williams and Co., Inc., of Columbus, Ohio, welded the shear support back into serviceable condition in 3½ hours using only 5 pounds of Ni-Rod "55".

Fractured on Friday

...back Shearing on Saturday

It was a black Friday . . .

The company's 8-ft. metal shear had broken in a freak accident.

It would take weeks to replace the part and would cost several hundred dollars.

Furthermore, the time couldn't be spared — the shear had to be always ready to handle emergency orders for cut-to-size pieces of metal.

What to do?

One of the company's welding specialists examined the gray cast iron shear support, and felt confident he could repair it.

Early Saturday morning he started . . .

First, he ground the fracture open to prepare the joint for welding. Then, using a ⅛" Ni-Rod "55"® welding electrode he laid the first bead. He carefully removed the slag and peened it — repeating this procedure until he had built up enough weld to go to a 5/32" Ni-Rod "55" electrode. He built the weld up above flush — — using five pounds of electrodes altogether.

The welding job was finished in about 3½ hours. The shear was back on duty Saturday — the welder had saved time and dollars for the company!

That's the kind of job welders are doing regularly with Ni-Rod "55" and usually without pre-heat or post-heat because it gives a sound, crack-free, nonporous weld. And Ni-Rod "55" is easy to use — it's stable-arcing with a minimum of spatter to give a smooth bead contour.

If you have a special cast iron welding problem, you can always call on Inco's Technical Service Section for help. In the meantime, write for a copy of the new folder on Ni-Rod "55".

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street, New York 5, N. Y.

INCO TRADE MARK

The WELDING JOURNAL

volume 33 June 1954 number 6

Effect of Power Supply Characteristics on Sigma Welding

The development of a satisfactory power supply for sigma welding to provide optimum arc performance and simple control

by W. H. Helmbrecht and R. L. Hackman

INTRODUCTION

THE use of sigma welding for the fabrication of nonferrous materials, high-alloy and stainless steels and, more recently, certain grades of mild steel has been notably successful. The development of this process has involved a thorough study of all of the factors influencing arc behavior, and an analysis of the relative importance of these various factors on welding performance. As the range of sigma welding applications has been extended, many improvements in shielding gas composition, apparatus design and electrode composition have been made to satisfy specific welding requirements. It has long been recognized, however, that welding results are affected by the characteristics of the power supply and that one of the most important process refinements that could be made would be the development of a power supply having operating characteristics designed especially for sigma welding.

For several years an extensive investigation has been conducted to correlate arc performance, as it is affected by the power supply characteristics, with welding results and process requirements. The principal objective of this work was the development of a satisfactory power supply which would provide optimum arc performance with a minimum of auxiliary control equipment. On the basis of all sigma and related "Unionmelt" welding experience, early consideration was given to the use of constant-potential-type power supplies.

Exploratory work was initiated in 1947 by suitably modifying conventional power supplies. Subsequently, the work was extended with the conversion of rectifier-type power supplies. Commercial application of the modified motor-generator type power supply were made in 1950. Practical laboratory and field experience obtained with these converted commercial units provided the information that was necessary in order to present power supply manufacturers in 1951, with specifications for a specially designed power supply for sigma welding. Recent production applications using a commercial power supply of this type have been successful and the welding results have verified the practical significance of this work.

SIGMA WELDING PRINCIPLES

Sigma welding is the practical and successful application of a unique process principle—that of using continuously fed welding wire as a consumable electrode for high-current-density arc welding within an envelope of shielding gas such as argon—and it depends upon obtaining balanced welding conditions for uniform arc operation. Theoretically, the welding operation is "automatic" in the sense that the welding arc is self-regulating when any two of the three variables, wire feed rate, arc voltage, and arc current, are fixed. The conventional power supply provides essentially constant-current output at any current setting. Constant-wire-feed rate is achieved by electronic control. Thus arc voltage or arc length under any given set of conditions is

W. H. Helmbrecht and **R. L. Hackman** are Development Engineers with the Linde Air Products Co., Newark, N. J.

Presented at Thirty-Fourth AWS National Fall Meeting held in Cleveland, Ohio, week of Oct. 19–23, 1954.

thereby fixed by the relative values of wire feed rate and arc current.

In practice, deviations do occur from the theoretically constant-wire-feed rate and constant current. Therefore, some variations in arc voltage result. However, arc regulation within acceptable limits has been realized for most flat-position manual welding as shown by the great variety of successful production applications of this type. Nevertheless, changes in voltage do affect such welding factors as penetration, bead shape, undercutting and, sometimes, maximum permissible speed. Many mechanized applications require greater arc voltage stability than can be obtained normally with constant-wire-feed operation. For this reason, distinctly different wire-feed-control systems are employed for mechanized and for manual sigma welding equipment when conventional power supplies are used.

Most sigma welding equipment for manual operation employs electronic means to obtain adjustable, constant-speed operation of an electric-motor-driven wire-feed mechanism. This means of control is used chiefly for three important reasons: First, it yields a higher degree of motor speed consistency than any other known and practical means. Second, remote speed adjustment is easily obtained. Third, the range of speed adjustment far exceeds that of any other means. In addition to the electronic control which regulates the rate of wire-feed speed during welding operation, voltage-sensitive relays assist arc initiation by preventing wire feed until the arc has been established. The use of constant-rate wire feed with conventional power supplies, referred to hereafter as conventional operation, requires proper adjustment of wire-feed rate and welding current to obtain the desired welding conditions. Either welding current or wire-feed rate may be established before welding is started. If the current is preselected, the wire-feed rate is adjusted after arc initiation to obtain the required arc voltage or length. If wire-feed rate is preselected the welding current is adjusted after arc initiation to approximately the correct value. Final adjustment of wire-feed rate is then made to obtain the proper arc voltage.

Most sigma welding equipment for mechanized operation is equipped with an electronic arc-voltage control. Basically this control functions as a servomechanism by "sensing" the arc voltage and automatically adjusting the wire-feed rate to maintain a preselected arc voltage. In order to assist arc initiation, an automatic wire inch down and retract system is included. The use of arc voltage control equipment with conventional power supplies, referred to hereafter as voltage control operation, requires proper adjustment of arc voltage and welding current to obtain the desired welding condition. The welding current is usually preselected and the arc voltage adjusted to obtain the desired value after arc initiation. This type of operation shows some advantages over conventional operation because the arc voltage is maintained constant even with deliberate changes in welding currents over a moderate range.

POWER SUPPLY STUDY

It is evident that arc conditions must be maintained relatively stable to obtain uniform welding results. While the use of auxiliary arc voltage control with conventional power supplies has been successful, it has added to the complexity of the welding equipment, particularly as other desirable operating features and associated controls were added. The development of a power supply designed to meet sigma welding needs required a basic study of the arc and power supply characteristics and a thorough understanding of the effect of power supply characteristics on arc performance.

The operating characteristics of a welding power supply are most easily visualized by means of the static volt-ampere curves. The characteristic curves for all conventional power supplies are similar in that as the output current increases the voltage rapidly decreases and for this reason they are described as "drooping." The conventional motor-generator type power supplies provide for adjustment of open-circuit voltage and welding current. A vast number of related characteristic curves can be produced, representing every possible combination of open-circuit voltage and welding current adjustment. Figure 1 illustrates the general nature of such characteristic curves. At any fixed open-circuit voltage setting, a family of curves exists, representing every value of current adjustment. In the interest of simplicity, typical families of curves are illustrated only for a high- and a low-open-circuit voltage setting. In general, all curve families overlap in the useful welding range and, as shown by the curves identified as *A* and *B*, any welding condition or operating point *O* may be obtained with more than one combination of open-circuit voltage and current settings. The number of characteristic curves available with conventional rectifier-type power supplies is limited to one family since the open-circuit voltage is fixed.

It should be realized that the characteristic curves usually referred to by the manufacturer of a welding power supply are determined by using a resistance as a substitute for the welding arc, and by measuring volt-

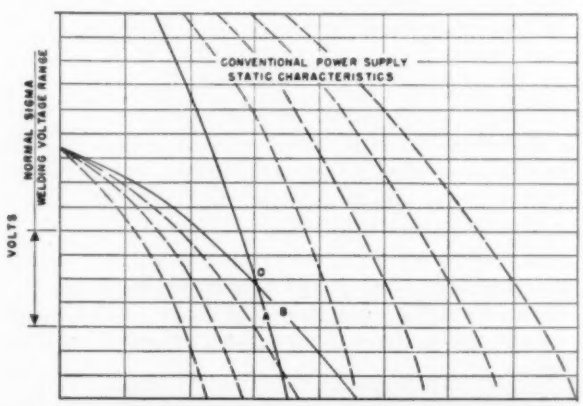


Fig. 1 Static operating characteristics of conventional power supplies

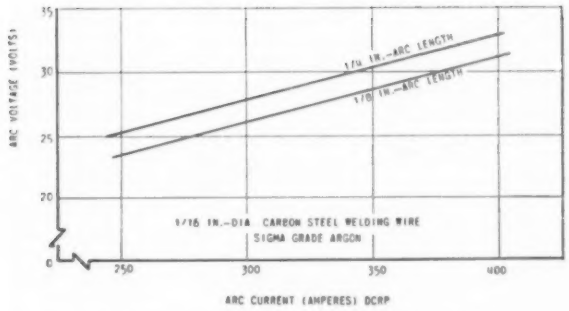


Fig. 2 Operating characteristics of the sigma arc

age and current at the output terminals of the power supply. In actual use the characteristic curves at the welding arc will differ from the published curves by the amount of voltage drop in the welding cables, connectors, clamps and welding jigs.

The arc characteristics determined for a wide variety of electrode materials and shielding gases show that for constant arc length, the general characteristics in terms of arc voltage and arc current are similar since the voltage increases as the current increases. Figure 2 illustrates these characteristics for $^1/_8$- and $^1/_4$-in. arc lengths using a mild steel electrode wire and sigma-grade argon shielding gas.

Figure 3, which combines the curves of Fig. 1 with Fig. 2, clearly illustrates the relationship of the arc and power supply characteristic curves. The intersections of these curves represent welding conditions or operating points of the arc. Operating point *O*, then, represents a welding condition, corresponding to a $^1/_8$-in. arc length, which may be obtained with characteristic Curves *A* and *B*. If the power supply is adjusted to obtain Curve *A* and the arc length increases from $^1/_8$ to $^1/_4$ in., due to a decrease in wire-feed rate, a new operating point at a higher voltage and lower current is established *R*. Similarly if the arc length decreases to $^1/_8$ in. as the wire-feed rate is restored, equilibrium is again reached at the original operating point *O*, illustrating the self-regulation characteristic of the arc. In practice these arc length fluctuations, which are caused by small variations in the wire-feed rate existing in practical wire-feed systems, are usually of much smaller magnitude and occur rapidly.

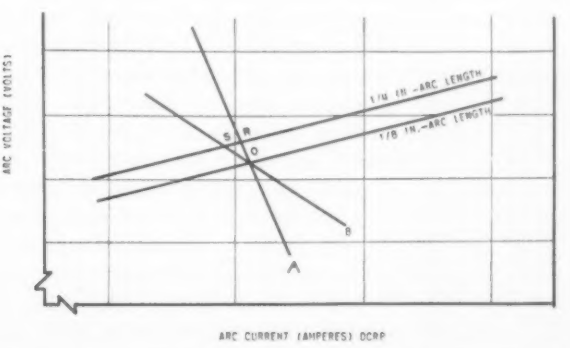


Fig. 3 Comparison of characteristics of conventional power supplies and arc

The self-regulating characteristic of the arc is, however, related to the power supply characteristic. Considering adjustment of the power supply to obtain Curve *B*, and change in arc length from $^1/_8$ to $^1/_4$ in. will result in a new operating point *S*, which corresponds to surprisingly different welding conditions than operating point *R*. Thus for a given change in arc length, the change in welding conditions resulting will depend on the power supply characteristic. Similarly for a given change in wire-feed rate, the corresponding changes in arc length and welding conditions will vary quite widely depending on the power supply characteristic.

Figure 3 further illustrates two other important factors affecting welding performance, namely, short circuit current and "burnback" occurrence. By extending characteristic Curves *A* and *B* to the very low voltage which exists when the electrode contacts the workpiece (short circuit conditions) it is apparent that the corresponding short-circuit current varies widely with the characteristic curve. Since available current is of major importance during arc initiation, the ease of arc initiation will therefore depend on the adjustment of the power supply. The characteristic Curves *A* and *B* are shown extended to a sufficiently high voltage to explain the mechanism of "burnback." If the wire-feed rate is reduced appreciably for a measurable length of time, or if the wire-feed rate is adjusted to an insufficient value for the current setting; the arc voltage will increase in accordance with the power supply characteristic curve until a sufficiently high voltage, usually about 32–33 v in argon is attained. At these voltages the arc will have sufficient length to be drawn from both the welding wire and the wire guide tube and fusion between the two will occur.

CONSTANT POTENTIAL TYPE POWER SUPPLY

Past experience definitely established that an absolutely constant-wire-feed rate could not be maintained in practical operation. Moreover, with welding power supplies having "drooping" characteristics, variations in wire-feed rate must be accompanied by corresponding variations in both current and voltage. With voltage control operation, voltage and current are maintained constant by appropriately controlling the rate of wire feed. Since changes in voltage are the most influential in affecting welding results, the logical approach to improving arc performance was to investigate the utility of welding power supplies having a flat volt-ampere characteristic as shown by Fig. 4. These units are referred to as constant potential-type power supplies. Under these conditions, the operating points at various arc lengths must necessarily be at the same voltage. Therefore, variations in wire-feed rate are reflected only by a corresponding change in arc current.

Further analysis shows that tremendously high short-circuit currents, which should assist arc initiation, may be expected from a power supply of this type. More-

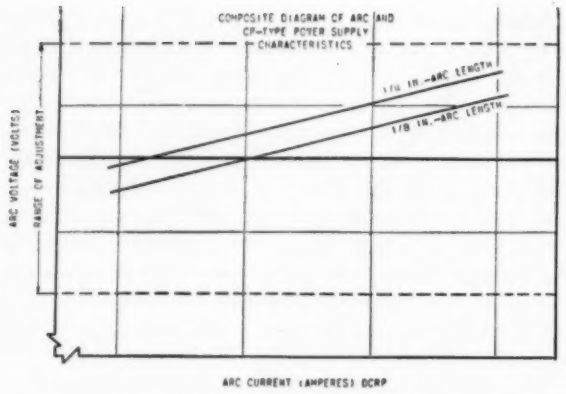

COMPOSITE DIAGRAM OF ARC AND CP-TYPE POWER SUPPLY CHARACTERISTICS
1/16 IN.-ARC LENGTH
1/8 IN.-ARC LENGTH
ARC VOLTAGE (VOLTS)
RANGE OF ADJUSTMENT
ARC CURRENT (AMPERES) DCRP

Fig. 4 Comparison of characteristics of constant-potential power supply and arc

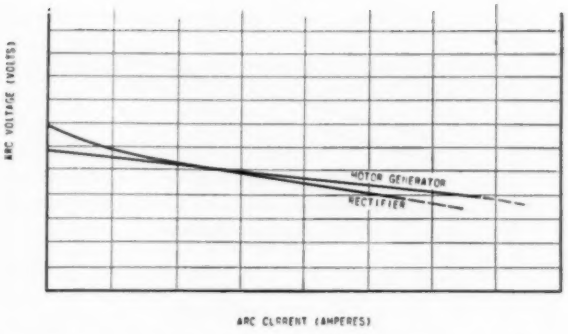


Fig. 5 Static characteristics of constant-potential power supply at the arc

over, the flat characteristic should drastically reduce the opportunity for burnback to occur since the open circuit and welding voltages are identical.

In order to obtain a constant-potential-type power supply for the early experimental work it was necessary to convert conventional motor-generator-type units. It was found possible to achieve the approximate volt-ampere characteristics desired by the use of a suitable voltage-regulating device employed in the field circuit of the generator. Conventional rectifier-type power supplies were later converted for constant potential operation by virtually eliminating all reactive components, paralleling two units and applying only one-half of the rated primary voltage. The results of welding tests using several converted power supplies on a wide variety of sigma welding applications did clearly establish the advantages of "constant-potential operation" over "conventional operation," even though optimum performance was not obtained. The power supplies converted for constant potential operation lacked two important qualities—high speed of response and high short-circuit current. This test work, however, did provide the necessary information to compile specifications for a constant-potential-type power supply which would provide optimum performance characteristics.

Subsequent sigma welding performance tests were made using two power supplies designed especially for constant-potential operation. One was a 600-amp compound-wound motor-generator-type unit and the other a 500-amp rectifier-type unit. Figure 5 illustrates the characteristic volt-ampere curves as measured at the arc for these power supplies. The characteristic curves show a slight departure from the ideal flat characteristic, in the amount of 1 v per 80 amp for the motor-generator type, and 1 v per 50 amp for the rectifier type. However, it should be emphasized that these curves represent the characteristic as measured across the arc. Therefore, the power supply characteristic is closer to a flat characteristic by the amount of voltage drop occurring in the 40 ft of welding cable employed in these tests.

Mechanized sigma welding tests were made comparing constant-potential operation with voltage control operation. Comparison of butt welds made in $^1/_2$-in. thick mild steel plate with each type of operation showed no detectable difference in the welding performance or welding results. Fillet welds produced in $^1/_{16}$-in. thick aluminum and mild steel were found to be of equivalent quality and contour. Burn through on arc initiation occurred, on about 10% of the welds made with arc voltage control; whereas, no evidence of this difficulty was found when the constant-potential-type power supply was used. This test indicated that the constant-potential-type power supply recovered after arc initiation much more rapidly than did arc voltage control equipment.

In view of the fact that both constant-potential-type power supplies exhibited some departure from a flat volt-ampere characteristic, a test was conducted to exaggerate the effect of variations in wire-feed rate and to simulate involuntary motions of a welding operator's hand. Bead-on-plate welds in the flat position were made on a plate which was oscillated vertically at the extremely high rate of 210 oscillations per minute. Oscillograph recordings of the arc voltage and arc current were made as shown by Figs. 6 and 7. The compound-wound motor generator, with its characteristic curve slope of 1 v in 80 amp at the arc, maintained the voltage within about $\pm^1/_3$ of a volt, while the current varied a total of 60 amp. The rectifier-type power supply, with its characteristic curve slope of 1 v in 50 amp at the arc, showed voltage deviations not in excess of $\pm^1/_4$ v with a total current variation of 25 amp. Analysis of these oscillographs clearly indicates that the constant-potential-type power supplies are responsive to each oscillation and they are capable of maintaining the arc voltage within very close limits. These oscillographs further illustrate that the power supply with the least characteristic-curve slope does not maintain the arc voltage as closely as the other power supply. The reason for the apparent paradox is the relative response characteristics of the two constant-potential-type power supplies. As the speed of response of a power supply is decreased, the change in voltage becomes relatively large before a compensating change in current can be made. Therefore, the change in current must be larger. If the speed of response is very low, "hunting" or uncontrollable oscillation of the power supply generally occurs. It is plainly evident that speed of re-

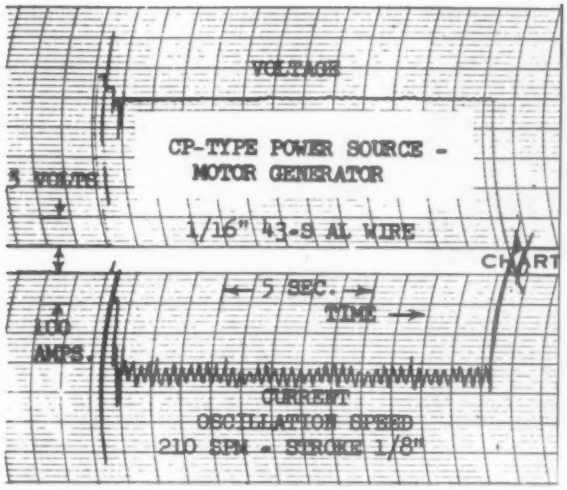


Fig. 6 Operating characteristics with constant-potential motor generator

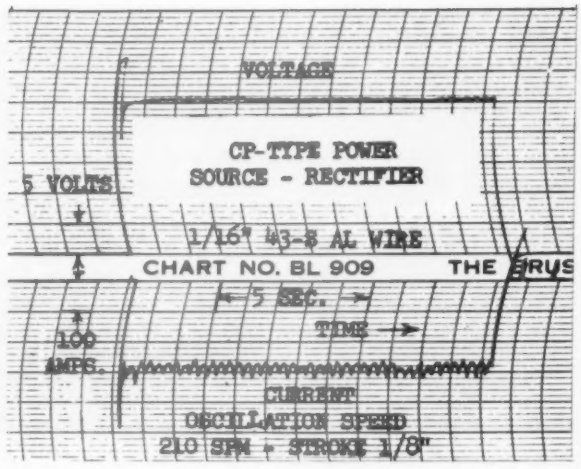


Fig. 7 Operating characteristics with constant-potential rectifier

sponse is just as important as the characteristic curve. It should not be inferred from these exaggerated tests, however, that the motor-generator, constant-potential-type power supply is necessarily inferior for practical welding applications. It is further apparent that the constant-potential-type power supply requires wire feed that is maintained as nearly constant as possible to prevent excessive current fluctuations.

Numerous manual sigma welding tests were made again to compare welding results obtainable with voltage control operation using an experimental control and constant-potential operation. The results of all hand welding tests are typified by the performance obtained in the preparation of overhead fillet welds on $^1/_4$-in. thick 61S-T6 aluminum. This test is a particularly critical one in that aluminum has been found to be extremely sensitive to fluctuations in arc voltage since porosity occurs below a critical value. The welds produced were of excellent quality and over-all appearance, with no obvious difference due to the process combination used to make them. By way of comparison, similar welds made using conventional operation resulted in some slight porosity directly attributable to voltage fluctuations.

Throughout this experimental work it was observed that exceptionally high short-circuit currents are obtained when the electrode makes contact with the workpiece and that arc initiation occurs in extremely short periods of time. Preliminary tests using equipment without controlled wire feed during arc initiation demonstrated that the arc apparently is established "instantaneously" regardless of electrode composition even when the wire-feed rate is adjusted to full welding speed. High-speed motion pictures taken at 3000 and 10,000 frames per second verify the nature of arc initiation. Photographic records of oscilloscope traces compare the current surge and the over-all time required for arc initiation using conventional and constant-potential-type power supplies. Figure 8 shows that the conventional power supply furnished a maximum surge of 650 amp which immediately fell to about 500 amp during most of the 0.5 sec required to recover to a steady-state welding condition. By contrast, Figure 9 shows that the constant-potential-type power supply furnished 1200 amp on short-circuit and recovered in 0.092 sec, or approximately one-fifth of the time of the conventional power supply.

The use of constant-potential-type power supplies with sigma welding equipment really simplifies the welding operation and the auxiliary control equipment. Sigma welding operation is established by preselecting the desired arc voltage, and adjusting the wire-feed rate to obtain the proper welding current. Actually, the remote control of wire-feed rate that is employed with the electronic speed control, becomes a remote current control. During the adjustment of welding conditions, there is little danger that burnback will occur, or that the electrode will plunge and stick to the workpiece.

Generally, the use of constant-potential-type power supplies for sigma welding provides an excellent means for obtaining automatic arc voltage control for those applications where highly controlled welding condi-

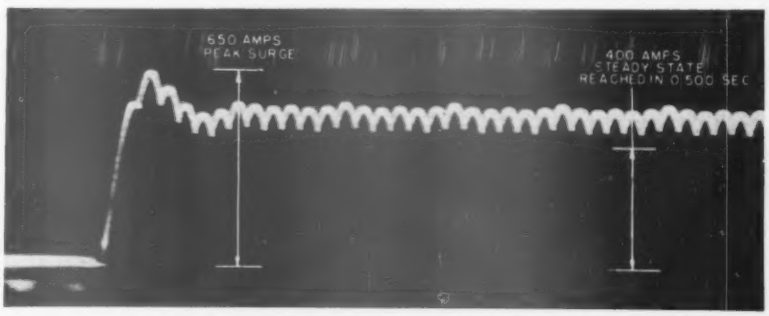


Fig. 8 Arc initiation with conventional power source

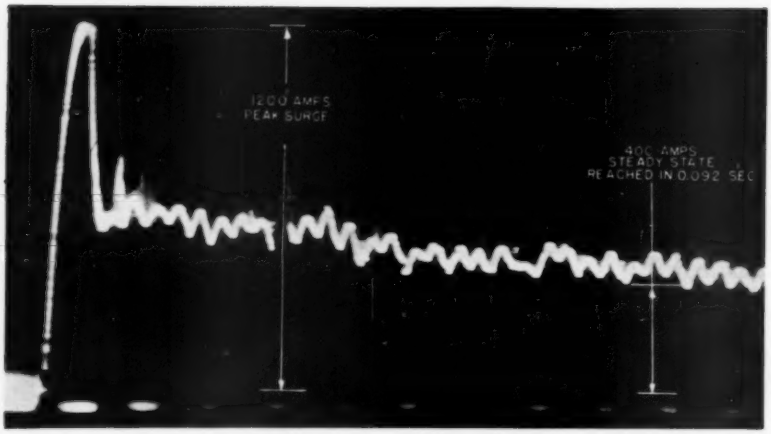


Fig. 9 Arc initiation with constant-potential power source

tions must be maintained. Constant-potential-type power supplies need not have a perfectly flat volt-ampere characteristic. However, the amount of departure tolerable at the arc is dependent upon the degree of voltage control necessary and the speed of response of the power supply. With satisfactory operation, the effect of current fluctuations obtained is not detrimental to weld quality or detectable in weld appearance.

SUMMARY

The results of all of this work have led to five significant conclusions relating to the several types of sigma welding operation:

1. Manual sigma welding using conventional operation has found wide acceptance and will continue to be satisfactory for numerous flat position applications where precise control of welding conditions is not necessary.

2. Manual sigma welding using constant-potential operation shows a marked advantage for position welding of aluminum and probably should be preferred for the position welding of other materials as well.

3. Mechanized sigma welding performance using arc voltage control operation is equivalent to that using constant-potential operation and for most known applications both are substantially superior to that using conventional power supplies with constant wire-feed equipment.

4. Mechanized sigma welding using arc-voltage-control operation or constant-potential-type operation will be preferred over conventional operation for all high-speed applications.

5. Constant-potential operation offers, over other process combinations, certain advantages, such as instantaneous arc ignition, simplicity of welding operation and relative freedom from burnback, all of which either cannot be otherwise obtained or can be obtained only by adding to the complexity of auxiliary control equipment.

SPECIAL PACKAGE OFFER—AWS CODES AND STANDARDS

The Society has made available a "package" arrangement whereby any individual, library or company may purchase a complete set of codes, standards, specifications and books on welding published by the Society and covering the subjects of Fundamentals of Welding; Training, Inspection and Control; Processes; and Industrial Applications. Complete set of these publications are listed under general classifications A, B, C and D of the 1953 Order Form which will be furnished upon request. In addition to these existing publications, two binders are supplied for containing same and *a 10-year service is provided whereby the subscriber automatically receives new or revised standards issued during the next 10 years.*

This complete "package" of present publications, binders and 10-year service is available to companies who support the Society through Supporting Company membership at a price of $25; members enrolled in the Member (B) Grade classification as well as libraries (public, school or other endowed) at a price of $35; members enrolled in the Associate Member (C) Grade classification at a price of $39 and to nonmembers of the Society at a price of $50.

In the instance where the 10-year service alone is desired (no binders or existing standards furnished), the price to Supporting Companies is $10; "B" members and libraries $17; "C" member $19 and nonmembers $27.

Your order should be accompanied by either check, money order or company purchase order and mailed to American Welding Society, 33 W. 39th St., New York 18, N. Y.

Inert-Gas-Shielded Titanium Brazing

Processes, procedures, metallurgical aspects and physical strength data in brazing and soldering titanium to itself and other metals

by Harlan L. Meredith

Abstract

The problem of finding a method for sealing the internal mechanisms of a titanium sphere against atmospheric conditions and leakage or chemical attack by certain floating and lubrication fluids stimulated a brazing and soldering research and development program by the North American Aerophysics Department in Downey, Calif.

The most desirable joining method was considered to be soft soldering. However, at that time there was little known about suitable joining processes, low melting metals or alloys and compatible fluxes which would effect adherence, bonding or alloying with titanium sufficiently enough to guarantee a good sound joint.

Preliminary experiments showed that titanium was brazable with enumerable silver-brazing alloys providing it was accomplished within an inert-gas-controlled atmosphere. This discovery led to the idea of brazing a solderable material to the titanium sphere component's subsequent jointing areas.

This paper deals with the processes, procedures, metallurgical aspects and physical strength data accumulated in developing a research production process for joining titanium to itself or other metals by either brazing or soldering.

BRAZING TITANIUM GUIDED-MISSILE COMPONENTS

Introduction

DUE to the absence of a commercially available soft soldering or silver-alloy brazing flux for titanium, the North American Aerophysics Materials Research Group was confronted with the problem of providing a suitable means with which a titanium sphere assembly could be hermetically sealed.

The sphere (Fig. 1) consists of five parts: two end caps, two semispheres and one center ring. Engineering specifications required the four joints to withstand a helium leak rate equal to or less than 2.5×10^{-6} cc/sec and the method used to seal the sphere assembly was to allow disassembling and reassembling at any time without injury to its contents.

An engineering evaluation of the sealing problem suggested that soft soldering would be the answer.

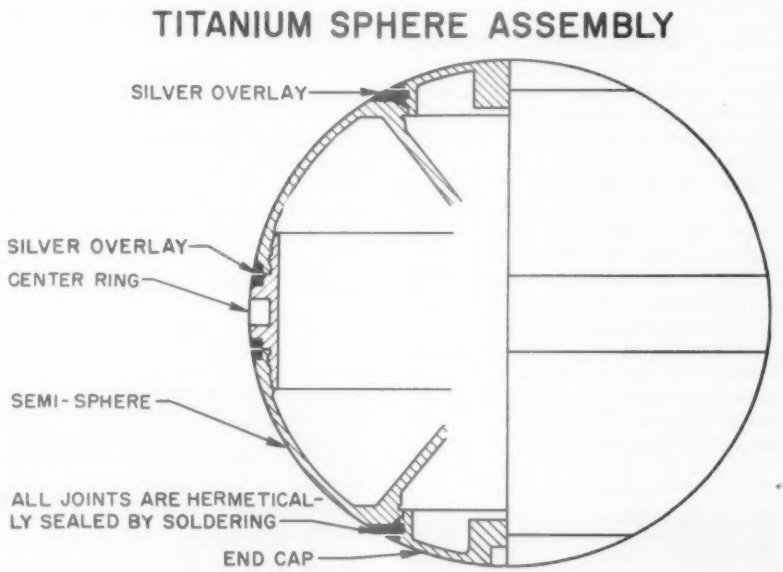


Figure 1

Brazing and Soldering Processes

Three procedures have been adopted to produce a hermetic seal by soldering. First, braze a solderable material within the sealing area or, second, provide a silver overlay within the sealing area. These two procedures allow soft soldering, at the sealing area, by conventional techniques. Or, third, solder directly.

The first process used for silver brazing dissimilar metals to titanium was an inert-gas-shielded induction heating process.

The silver overlay process* is accomplished with a Heliarc torch using a high-frequency alternating-current welding transformer.

Soldering directly to titanium is also done by the Heliarc process.

Induction Brazing

Preliminary brazing tests revealed that titanium is a very brazable material, but the ability of the metal to absorb oxygen, nitrogen and hydrogen is detrimental at brazing temperatures. Because titanium is such a reactive metal and its thermal conductivity is so low, a suitable brazing process is considered to have the following properties: (1) Quick, local, uniform heating; (2) inert-gas protection; (3) moderate cooling.

Figure 2 shows an inert-gas induction brazing platform that was developed for brazing without flux. The platform is shown in the brazing position. The small black box behind the platform is an Ajax focus inductor. To the left is a partial view of the focus inductor's power source, a 20-kw Ajax induction spark gap converter.

The induction brazing platform was de-

Harlan L. Meredith is Research Engineer of the North American Aviation Co., Aerophysics Materials Research and Process Development Group, Downey, Calif.

Lecuture at the Western Metal Cangress held at Hotel Statler, Los Angeles, Calif., March 23-27, 1953.

Presented at the AWS National Spring Meeting held in Houston, Tex., week of June 16-19, 1953.

* "Patent Pending to H.L. Meredith, assignor to North American Aviation, Inc. Los Angeles, Calif."

signed to enable the utilization of the three titanium brazing requirements mentioned before. Quick, local, uniform heating is afforded by the focus inductor work coil shown surrounding the titanium shear specimen within the insulated jig fixture (Fig. 3). Inert-gas protection is produced when the bell jar assembly is lowered and forms a seal on the platform base plate. When the brazing chamber is thus affected, a vacuum is taken on the chamber and then an inert gas is allowed to purge the brazing chamber by passing into the gage side, circulated in the chamber and allowed to escape through an outlet orifice.

Filler Metal Alloying Characteristics with Titanium

During the preliminary inert induction brazing tests conducted in June 1951, a terrific amount of intermetallic alloying was found to exist within the silver-alloy brazed joints at the interfaces of the titanium-silver alloy zones.

The resulting joints were very strong but they were also very difficult to machine, displaying varying degrees of hardness throughout the brazed joint. This condition was very unsatisfactory from the standpoint of tool wear and joint fracture during finish machining.

In order to determine the relationship between the joint strength and resulting metallurgy of each different type of filler metal employed for brazing, a shear strength program was initiated.

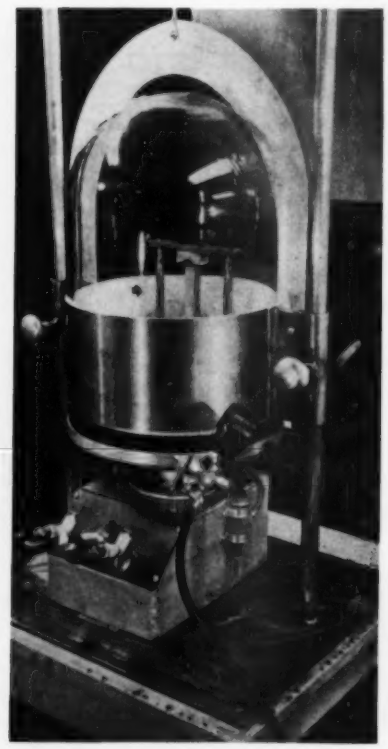


Fig. 2 Induction brazing platform

Shear Specimen—Joint Design

The strength of joints brazed with compatible filler metals is influenced by several factors:

1. The cleanliness of the brazed joint prior to and during brazing.
2. The degree to which the filler metal will wet and bond with the parent metal.
3. The clearance between the interfaces of the parent metal at the brazed joint or the resulting thickness of the brazing alloy layer in the joint.
4. The strength of the parent metal (metals being joined).
5. The physical requirements of the brazed joint.

The first three factors are compulsory prerequisites for obtaining a suitably brazed joint with titanium. In order to fulfill these requirements, the specimen shown in Fig. 4 was designed to provide an interstice regulated clearance, self-aligning tongue and groove, stress riser free and pure tension-shear joint.

General Brazing Procedure

1. Cleaning. Clean the general joint area by vapor blasting or picking with orthophosphoric acid solution (50%) at 150° F. After each method of cleaning, rinse the affected area well with water and then dry with a compressed air blast.

2. Preplacing Filler Metal. Immediately after cleaning, preplace the filler metal in the joint interstices by laying 0.002- to 0.005-in. thick ribbon stock on top of the grooved member and then force the filler metal in place by driving the tongue specimen into the groove.

3. Mounting Specimen in Jig. Place the assembled specimen in the insulated jig, as shown in Fig. 3, and tighten securely to assure against movement during heating.

4. Inert-Gas Purging. Slide the bell jar down into place as shown in Fig. 2. Pass an inert gas through the gage side and exhaust at the opposite side through the quick shut-off valve. The purging operation generally takes 10 to 15 min. This may be lessened by evacuating the system with a vacuum pump. Purge the system at a minimum rate of 10 lpm.

5. Heating—Brazing. Apply the induction heat until the filler metal melts and completely flows through the joint interstices. Adjust or tune the input power during brazing to prevent overheating the part.

6. Cooling. Cool the brazed joint moderately slow to prevent excessive build-up of thermal stresses. Allow the inert gas to purge the chamber until the specimen is below 900° F.

These results were very gratifying for they showed how versatile pure silver is as a brazing filler metal. As an engineering tool pure silver may be used for low-strength sealing, high-strength primary jointing or medium-strength secondary jointing.

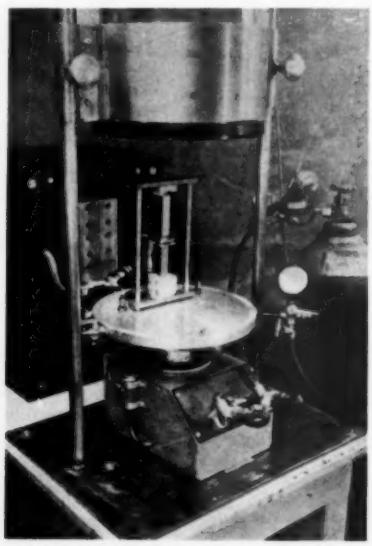


Fig. 3 Induction brazing platform

SUMMARY OF BRAZING RESULTS

Preliminary Brazing Results

The first lot of "indusivbrazed" titanium tension-shear specimens, shown in Fig. 5, was obtained with considerable ease by following the General Brazing Procedure.

The reason for selecting the pure silver, silver-copper eutectic binary alloy and the silver-copper-cadmium-zinc quaternary alloy was to obtain shear strength values

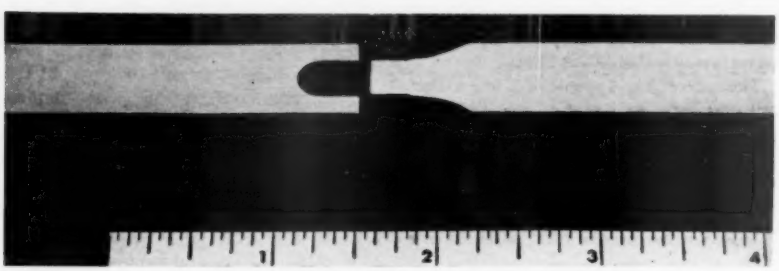


Fig. 4 Joint design—tension-shear brazing specimen

and comparable metallographic photomicrographs.

The first lot of "indusivbrazed" titanium tension-shear specimens was structurally tested on a Riehle Universal testing machine, registering in the 0–20,000 lb range. Elongation in inches per inch was obtained with a destructive testing 2-in. gage length and the ultimate shear allowable for the joint was computed by assuming a uniform brazed area of 0.375 sq in. (neglecting small fillets) for all specimens.

The joint area was precalculated such that all fractures would occur along the jointing interface. When joint fracture was indicated by the testing machine the load was released such that the specimen was not pulled apart. In this way elongation could be measured as accurately as possible without postfitting.

The results of the preliminary shear strength tests are shown in Table 1. Two specimens were retained for metallurgical tests, one brazed with pure silver and the other brazed with the silver-copper eutectic brazing alloy.

On the merit of these results and metallography studies several other binary and ternary brazing alloys were selected for more shear strength and metallurgical studies.

Table 1—Preliminary Titanium Brazing Results, Using Double-Lap Tension Shear Specimens Made from MST Grade IV Titanium

Joint filler	*Filler melting point, ° F*	*Heating time, min*	*Total elongation, in.*	*Failing load, lb*	F_{su}, *psi*
Ag	1761	4.0	0.0088	8175	21,800
Ag	1761	3.0	0.0084	8300	22,100
Ag	1761	1.75	0.0076	8500	23,000
Ag	1761	1.50	0.0064	9040	24,100
Ag-Cu	1435	1.33	0.0084	7605	22,300
Ag-Cu	1435	1.0	0.0052	9275	25,000
Ag-Cu	1435	1.0	0.0042	7050	18,800
Ag-Cu	1435	0.833	0.0040	7300	19,500
Ag-Cu-Cd-Zn	1125	1.0	0.0034	6250	16,700
Ag-Cu-Cd-Zn	1125	0.75	0.0040	7675	20,500

Shaft Insert Lap Joint Design

Examination of the first lot of brazed specimens showed that the joint interstice widened appreciably and that the resulting interface alloying was more predominant at the corners of the double-lap tension-shear specimen.

Nonuniform interface alloying was due to the type of magnetic field developed by using a two-turn helical induction rectangular work coil; coupled with the relative mass of the corner with respect to the sides of the double-lap specimen. In short, the rectangular specimen could not be heated uniformly enough with a simple work coil.

To rectify this condition a shaft insert lap joint design was incorporated.

The results of these modifications are shown in the following Titanium Brazing Data Chart (Table 2).

METALLURGICAL EXAMINATIONS

On the merit of the preliminary experiments all copper-bearing silver-brazing alloys were ruled out.

During the course of this investigation metallurgical examinations were made to determine the significance between the time, temperature and shear strength of joints brazed with pure silver.

The intent of the following discussion is not to define the metallurgical occurrences and sequence of behavior but is to point out to the layman the significance and benefits of certain joint designs, and shear strength variables which are determined by brazing temperatures and time at those temperatures.

Figures 6, 7 and 8 show a sequence of change in joint interstice width, identification of pure silver microstructure interface diffusion layer and microstructure of a partially formed new solid phase (intermetallic compound of titanium and silver).

Joint Interstice Width

Figures 6 and 7 are photomicrographs of a double-lap shear specimen and Fig. 8 is a photomicrograph of a shaft insert lap specimen. These photomicrographs were taken at 250 magnification. Comparison of the interstice width shows that after brazing the joint interstice of the double-lap joint is approximately twice that of the shaft insert lap joint.

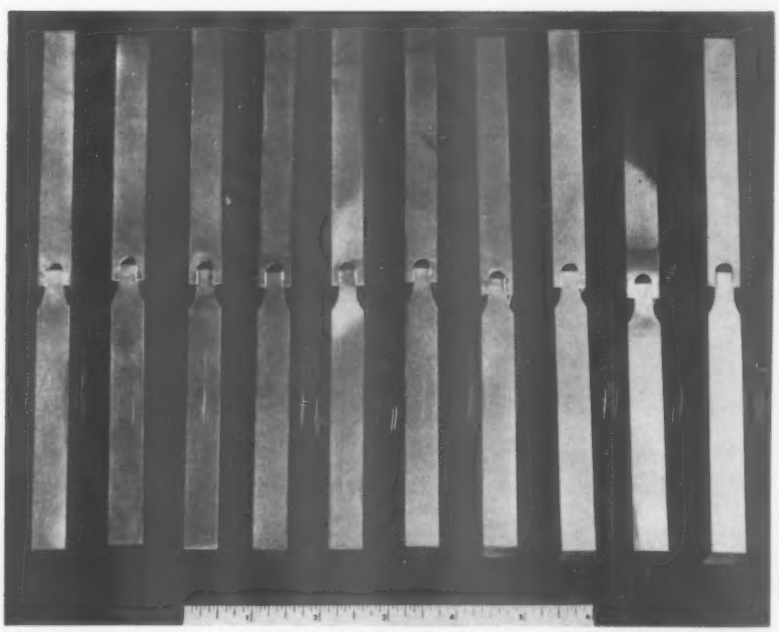


Fig. 5 Tension-shear specimens induction brazed with pure silver, a silver-copper eutectic and Easy Flo No. 45 silver-brazing alloys, shown, respectively, left to right

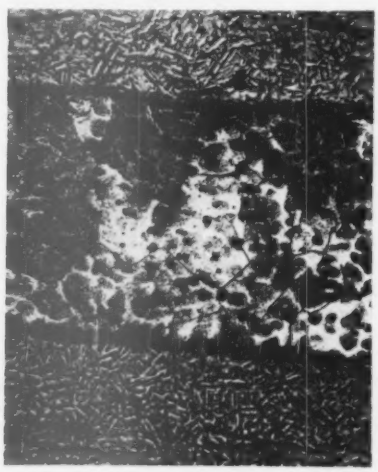


Fig. 6 Photomicrograph of an inert-gas-shielded induction silver-brazed joint

This photomicrograph shows the microstructure of both the MST Grade III titanium and pure silver as developed by fast brazing cycles. The dark splotches are due to etching difficulties encountered in attempting to show both microstructures simultaneously.

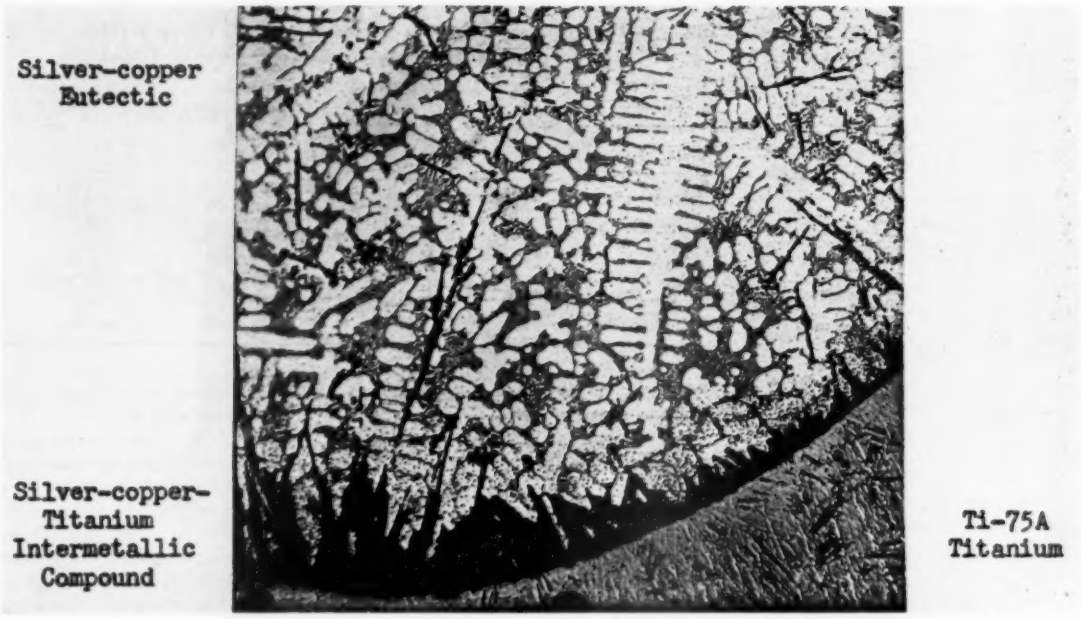


Fig. 7 Photomicrograph of an inert-gas-shielded induction silver-copper cast and bonded overlay. Magnification × 250

Ordinarily the joint strength is dependent on the interstice size. The nominal interstice is recommended at 0.003 in. for optimum joint strength and machining tolerances. However, other reporters have indicated that there is no significant difference in strength levels when the joint interstice is in the range of 0.001 to 0.010 in.

Examination of Table 2 shows this to be true. But other considerations should be taken into account, especially when the induction brazing process is used. Wide interstices should be filled completely and pure silver is not inexpensive. Also, pure silver upon heating absorbs appreciable amounts of oxygen and when filling large gaps it will evolve oxygen upon solidification and the resulting joint will be porous.

Comparison of Figs. 7 and 8 shows a different microstructure within the joint interstice. Both of these photomicrographs were taken from specimens which had been brazed by following the General Brazing Procedure as outlined in this report. The time for brazing was 1 min. Actually the shear strength of both was the same because pure silver remained through the center of the interstice, but the formation of a stronger joint structure was developed further in the same time with the shaft insert lap joint design than with the double lap joint design. Hence, by this reasoning, it can be said that indirectly narrow interstices ultimately result in higher shear strengths and cost less from the standpoint of amount of filler metal and brazing time.

As a comparison this photomicrograph (Fig. 7) shows the type of microstructure obtained when silver-brazing alloys *containing copper* are used. This particular photomicrograph was made of an induction cast and bonded joint, during experiments involving the development of silver overlaying titanium. The silver brazing alloy used is a silver-copper eutectic alloy, containing 72% silver and 28% copper. The titanium (bottom) is Ti-75A.

The microstructure of the top large portion is a Ag-Cu eutectic and the layer at the interface is a complex intermetallic compound of silver-copper-titanium.

This photomicrograph (Fig. 9) shows the microstructure of the MST Grade III titanium and pure silver joint interstice with emphasis on the diffusion layer in the reaction zone.

The extent of the discontinuous layer in the new solid phase varies in depth across the joint interstice with time and temperature. The new solid phase is an intermetallic compound of titanium and silver. The TiAg compound is apparently formed by a binary reaction in which the solid phase (titanium) and the liquid phase (silver) react during cooling to form a second solid phase (the resulting reaction zone).

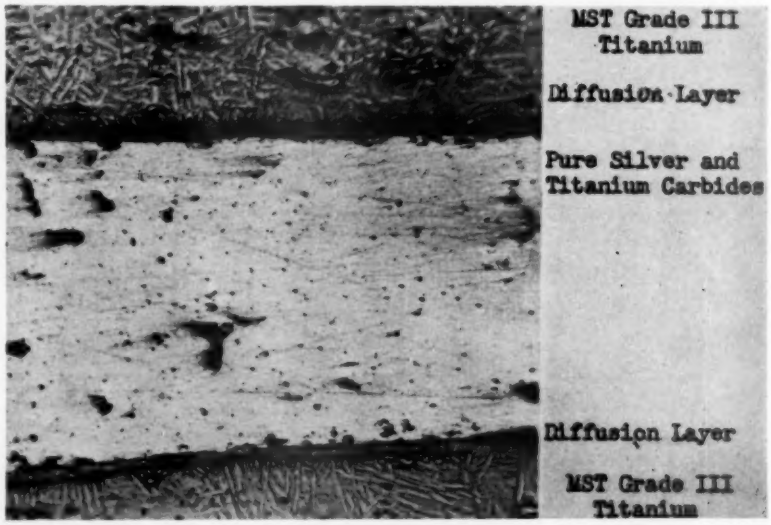


Fig. 8 Photomicrograph of an inert-gas-shielded induction silver-brazed joint (double-lap specimen). Magnification × 250

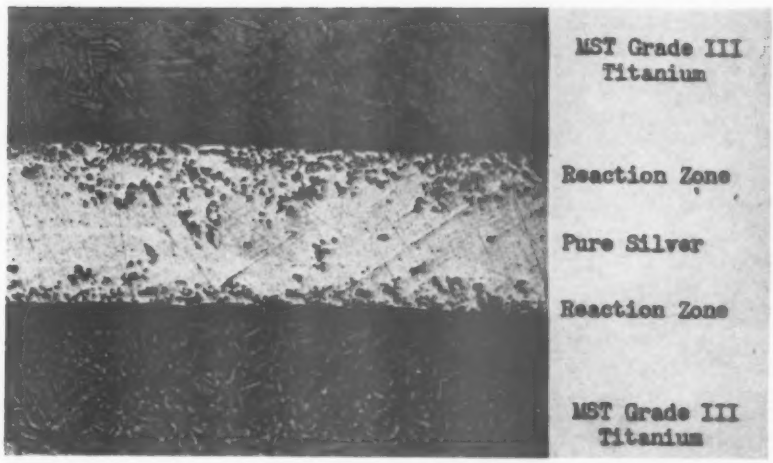


Fig. 9 Photomicrograph of an inert-gas-shielded induction silver-brazed joint (shaft insert lap specimen). Magnification × 250

Table 2

TITANIUM BRAZING DATA
PER INDUSIVBRAZING PROCESSES

PARENT MATERIAL	BRAZING FILLER METAL	JOINT DIMENSIONS DIA OR WIDTH	LENGTH	AREA	ULT. SHEAR ROOM TEMP. PSI	JOINT DESIGN
MST. GRADE IV COML. PURE HOT FORGED RECT. BAR	FINE SILVER .003" SHIM STOCK PREPLACED WITHIN JOINT INTERSTICES	.750 INCHS .750 .750 .750 .382 .357 .384 .384	.250 INCHS .250 .250 .250 .250 .250 .260 .260	.375 SQ IN. .375 .375 .375 .191 .179 .200 .200	21,800 22,133 22,666 24,106 19,200 22,000 21,600 21,800	DOUBLE LAP
MST. GRADE III COML. PURE FORGED RD. BAR-ROUGH TURNED.	FINE SILVER .062" DIA. WIRE RING PREPLACED OUTSIDE JOINT INTERSTICES (.002)	.495 .500 .497 .494 .494 .493 .492 .494 .491	.250 .250 .312 .320 .320 .310 .320 .330 .340	.369 .393 .487 .497 .497 .480 .495 .512 .524	18,400 21,600 20,700 22,900 25,800 23,100 20,100 21,300 23,700	SHAFT INSERT LAP
MST. GRADE IV	SILVER-COPPER EUTECTIC-BINARY AL .002" SHIM STOCK PREPLACED WITHIN JOINT INTERSTICES	.750 .750 .750 .750	.250 .250 .250 .250	.375 .375 .375 .375	20,266 24,733 18,800 19,466	DOUBLE LAP
MST. GRADE IV	SILVER-MANGANESE BINARY ALLOY .005" RIBBON STRIP PREPLACED WITHIN JOINT INTERSTICES	.733 .742 .745 .746 .750	.250 .250 .250 .250 .250	.367 .371 .373 .373 .375	21,400 20,400 20,400 21,000 21,500	DOUBLE LAP
MST. GRADE III	SILVER-COPPER-TIN TERNARY ALLOY .002" RIBBON STRIP PREPLACED WITHIN JOINT INTERSTICES	.499 .499 .497 .497	.230 .230 .280 .220	.361 .361 .437 .343	16,000 23,900 21,000 16,500	SHAFT INSERT LAP JOINT DESIGN MODIFIED TO REDUCE TEARING AT TAB ENDING
MST. GRADE IV	Ag-Cu-Cd-Zn QUATERNARY ALLOY .003" RIBBON STRIP PREPLACED WITHIN JOINT INTERSTICES	.750 .750	.250 .250	.375 .375	16,666 20,466	DOUBLE LAP
MST. GRADE III	Ag-Cu-Cd-Zn QUATERNARY ALLOY .003" RIBBON STRIP PREPLACED WITHIN JOINT INTERSTICES	.499 .496	.480 .510	.750 .790	25,700 15,300	SHAFT INSERT LAP
MST. GRADE III JOINED TO 18-8 CRES BAR TYPE 321	SILVER-COPPER .062" DIA. FINE SILVER WIRE PREPLACED OUTSIDE JOINT INTERSTICES-CRES JOINT AREA (HOLE) COPPER PLATED (.0015 IN.)	.500 .496	.650 .590	.020 .92	19,500 18,000	SHAFT INSERT LAP

JOINT DESIGN RECOMMENDATIONS
1. MATERIAL: BASE-COML. PURE TITANIUM FILLER-FINE SILVER
2. TYPE OF JOINT-SHAFT INSERT LAP
3. JOINT STRENGTH-ULT. SHEAR: 22,000 PSI (ROOM TEMP.)

Parent Metal Joint Strengths

Figure 10 shows a partially formed discontinuous new solid phase of an intermetallic compound of titanium and silver. If this new phase was not discontinuous and extended throughout the joint interstice the shear strength of such a joint would be equivalent to the tensile strength of annealed commercially pure titanium.

Cursory brazing tests involving the formation of a new solid phase were made by following the General Brazing Procedure with the exception of time and temperature range. Several tests were made by heating the shaft insert lap specimens up to 1761° to 1900° F and holding the specimen at that temperature for 15 min. Destructive tension-shear tests revealed that the ultimate shear was 19,500 psi. Metallurgical examinations revealed that the joint interstice did not contain a complete and uniform formation of the TiAg compound. Follow-up tests involving brazing at 2200° to 2300° F and holding for 15 min produced better results. Destructive tension-shear tests resulted in parent metal failures (32,000 to 36,000 psi shear ultimate). Of course the heat-affected area resulted in excessive grain growth and lowered the ductility but this condition may satisfy certain applications.

CONCLUSIONS

1. Brazing Process

1.1. Quick, local, uniform heating coupled with dry inert-gas protection around the heat-affected zone are the basic process requirements for brazing titanium to titanium effectively.

1.2. Induction brazing minimizes voids along joint interfaces and by restricting the heat-affected area prevents the total part from being affected by grain growth such as is experienced with furnace brazing.

1.3. Perfectly sound brazed joints can be guaranteed by preplacing fine ribbon or shim stock in joint interstices.

1.4. Joint cleanliness is of prime importance. When employing pure silver as the filler and obtaining a Ti Ag compound for high strength with moderate ductility it is important that the joint not only be metal bright and free from foreign impurities but, also, the joint surfaces must be free from the TiO surface phase.

2. Filler Metal

2.1. Pure silver is one of the better brazing filler metals.

2.2. Silver - manganese shows great promise as a good filler metal. It is relatively more expensive than pure silver.

2.3. Copper-bearing brazing alloys should be avoided for joining titanium to titanium until consistent strength levels may be obtained by special process procedures.

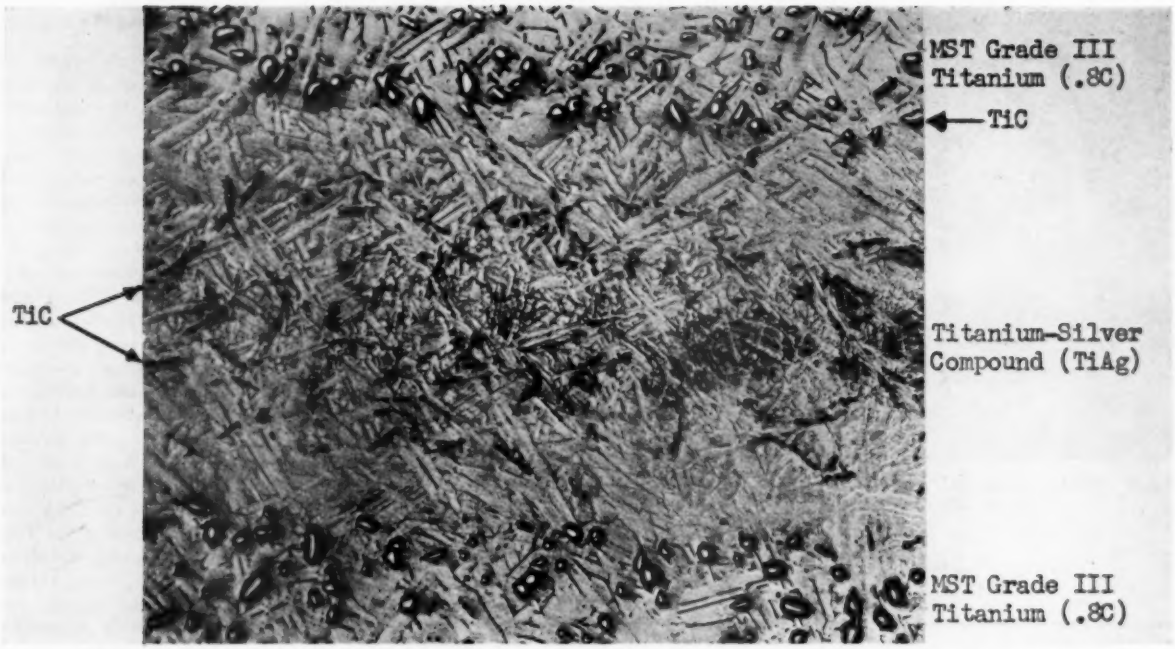


Fig. 10 Photomicrograph of a high-strength titanium-silver-brazed joint interstice. Etchant used: 1% Hf, 10% HNO_3 in water. Magnification × 250

3. *Metallurgical Aspects*

3.1. When certain fluid lubricants (restricted information) are used and will contact the brazed joint, short brazing cycles must be employed to avoid formation of the Ti-Ag compound because it is attacked by the fluid lubricants and causes subsequent intergranular corrosion.

3.2. High-strength silver-brazed joints are found to contain a uniform and complete formation of the Ti Ag compound throughout the joint interstice.

3.3. High temperature (2500° F) and greater time (10 min) at temperature are required for obtaining parent metal joint strength. This is due to the slow reaction between the molten silver and solid titanium. The titanium atoms must pass through the first Ti Ag layer which forms after the initial flow of silver over the joint surfaces and as the layer increases in thickness the titanium atoms must subsequently go further which takes more time.

4. *Joint Design*

4.1. The shaft insert lap joint design is preferred as compared to the double- or single-lap joint design. The shaft insert lap joint is symmetrical. Minimum coupling action is obtained when loading in tension. Also, providing the outside wall thickness of the hole member is thin as compared to the shaft diameter, uniformity with induction heating coils is more easily obtained and consequently uniform wetting and alloying by the filler metal may be assured. Furthermore, concentricity tolerances are more easily maintained without employing holding fixtures.

4.2. The joint spacing between the interfaces may vary appreciably with little loss in strength. However, as the joint spacing increases, greater time at a specific temperature is required to obtain uniform joint strength levels.

4.3. Shear strength results show that no gain in strength is obtained with narrow interstices. The same strength may be obtained with a 0.001- or 0.010-in. interstice. The difference gained in using a 0.001-in. interstice over a 0.010-in. interstice is a relatively shorter brazing time and less filler metal.

5. *Joint Strength*

5.1. Shear strengths equivalent to the tensile strength of annealed commercially pure titanium may be obtained by using joint interstices of 0.002 to 0.003 in., pure silver filler metal preplaced within the joint interstice, brazing temperatures maintained at 2100° to 2500° F and held for 15 to 10 min, respectively, after the complete flow of the filler metal is observed.

5.2. Shear strengths in the range of 24,000 to 27,000 psi may be obtained by using joint interstices of 0.002 to 0.005 in., pure silver filler metal preplaced within the joint interstice, brazing temperature maintained at 1900° to 2100° F and held for 15 to 25 min, respectively, after the complete flow of the filler metal is observed.

5.3. Shear strengths in the range of 20,000 to 22,000 psi are obtained by using joint interstices of 0.002 to 0.003 in., pure silver filler metal preplaced within the joint interstice, brazing temperature maintained at 1800° to 1900° F for the period of time required to allow the filler metal to flow completely throughout the joint interstice.

ACKNOWLEDGMENTS

The special assistance provided by the various personnel in the North American Aerophysics Department is acknowledged with appreciation.

Specific acknowledgment is made to the following personnel who assisted materially with this investigation: Blair Molander, Supervisor, Metallurgical Laboratory; Dr. N. A. Tiner, Metallurgist; and John Gilmore, Metallographer.

New Results in Tool and Die Welding

Repair of sharp cutting edges of high-speed tools and chips or cracks in dies and punches

by Robert Groman

THE majority of people working with tools and dies are familiar with the present methods of repair and salvage with oxy-acetylene torch and electric arc-welding equipment. Much has been written about procedures for such repairs and their use is increasing daily. More and more people are realizing the savings from tool and die salvage welding.

However, there is a very big field in which very little work has been done because of the specialized equipment required and the extensive training necessary to complete the salvage work (reheat treatments, etc.). Examples are the repair of sharp cutting edges of high-speed tools, small chips or cracks on plastic dies, punches, clicker dies as used in the shoe industry, etc.

Building up a sharp cutting edge on a high-speed tool such as a drill or reamer with the electric arc is very difficult because of burning the sharp cutting edges of the tool. Plastic dies are very intricate in design and almost impossible to weld with the electric arc. Annealing of the base metal is very detrimental when the oxy-acetylene torch is used.

Because of these problems a survey was made to determine what could be done to induce people to do more salvage welding and show them the savings that could be had by so doing.

The survey indicated 85% of the tool and die shops and tool departments in large plants are equipped with oxy-acetylene torches and electric arc machines (mostly direct current).

The survey also indicated that the majority of people doing repair and salvage work would give more of consideration to the repair of tools and dies providing it did not entail a capital investment of new equipment.

As a result the carbon arc method was introduced. *Not* the carbon arc torch which employs the twin carbons, but the single carbon method using a d-c machine, straight polarity.

For this type of work, a special coated carbon electrode has been developed. This special coated carbon electrode has a mineral and metallic coating which has produced phenomenal results equaling in importance the introduction years ago of the coated mild steel electrodes.

The special coated carbon electrode is used at lower amperage giving it longer life, greater workability and gas coverage similar to metallic arc welding.

The single carbon method is excellent because it provides a pin point source of heat, extremely localized, which will melt the base metal as soon as the arc is struck.

The carbon arc method produces welds that are spatter free and, if the proper technique is used, no undercutting will occur adjacent to the weld deposit.

The filler metal used is the special low-watt input tool steel electrode used for conventional electric-arc welding. The prescribed technique used is very similar to torch welding, as follows:

1. Put a taper point on the coated carbon electrode using a grinding wheel.
2. Grip the special coated carbon electrode on the brushed end in an electrode holder.
3. Place the holder in the right hand.
4. Hold the special low-watt input tool steel electrode in the left hand and feed it into the arc as soon as the arc has started.

Figure 1 shows a welder and the angle of the special coated carbon electrode and holder in one hand and the special low-watt input tool steel electrode in the left hand. In this case the welder is using a conventional electrode holder; sometimes the spring tension in this

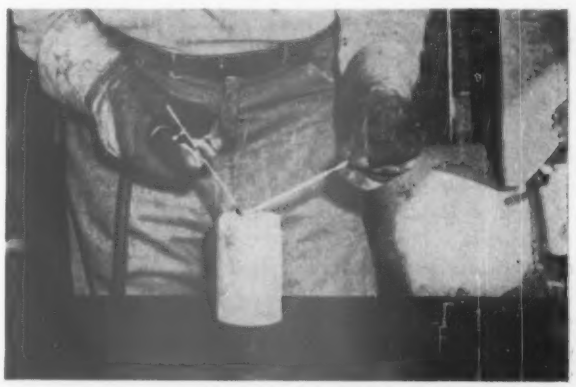


Fig. 1 Welder prepared to build up tool steel. Coated carbon electrode (in holder) and low-watt input tool steel electrode are held at the correct angle

Robert Groman is Director of Applied Welding Engineering, Eutectic Welding Alloys Corp., Flushing, N. Y.

Presented at the Thirty-Fourth National Fall Meeting, held in Cleveland, Ohio, week of Oct. 19-23, 1953.

type holder is too great for use with the small size coated carbon electrodes. If such is the case, cut off a small piece of copper tubing (1 in. long) and flatten it until the stick carbon has a snug fit, then grip the copper tube and no breakage of the coated carbon will result.

The recommended procedure is to grind out all defects in the die or tool so as to remove all chipped or broken areas. Preheat the die or tool to 400° F (blue heat).

An excellent method of determining the preheat temperature is to use temperature-indicating materials. For example, crayons will accurately indicate a specific temperature in the base metal within 1% of the specified temperature. If such materials are not available, one may watch the base metal for the color range.

Use a small carbon electrode, preferably $^1/_8$ and $^1/_4$ in., set the arc machine at 60 amp or less. Use a $^3/_{32}$-in. diam size special low-watt input electrode of the type of steel being welded, oil hardening low-watt input electrode for oil hardening steel or high-speed low-watt input electrode for high-speed steel, etc.

While there might be wide variations in the analysis of tool steels, the heat treatments, in each respective classification, are similar. Therefore, in welding it is not a question of matching the analysis of the steel, but of matching the heat treatment in its classification as closely as possible.

Strike the arc with the coated carbon electrode and feed the special low-watt input tool steel electrode into the arc using the torch welding technique. Build up the chipped area until the repair is completed. Excessive puddling is not necessary nor desirable.

Figure 2 shows the start of the actual welding operation. The welder is feeding the special low-watt input tool steel electrode into the arc. Never at any time maintain an arc length greater than $^1/_8$ in. between the end of the special coated carbon electrode and the part being welded.

Peening with a small hammer is recommended immediately after each pass or whenever the welding has been stopped. The chief effects of peening consists of relieving shrinkage stresses and improving the metallurgical structure of the weld deposit.

Sometimes peening is overemphasized and the tool welder will use a large hammer, thinking of forging the deposit. This must be avoided as too heavy a hammer blow will fracture the deposit and cracking will result. Always use a small hammer and a light hammer peening.

On corners or sharp edges, leave all of the extruded coating on the filler metal electrode. If a fillet weld is to be made, it is advisable to remove 50% of the coating on the filler metal electrode, either by grinding or breaking it off with a hammer. Caution—never at any time remove more than half of the coating. If too much of the coating is removed, the weld deposit will be brittle, low in tensile strength and considerable porosity will be evident. Much can be derived from the alloying elements of the coatings as they help to compensate

Fig. 2 The arc is struck and the electrode fed into the arc. An arc length no greater than $^1/_8$ in. should be maintained

the percentage of alloying elements lost during the welding operation.

When special low-watt input tool steel electrodes are used as a filler metal, the deposits are air hardened, as applied. On hardened sections, complete heat treatment, other than drawing or tempering, is generally not necessary.

After the deposit has cooled, rough grind the surface of the weld deposit, postheat or temper the weld deposit to the draw range of the filler metal used.

1. Oil hardening, 300–400° F.
2. Air hardening, 600–900° F.
3. Water hardening, 250–450° F.
4. Hot working, 700–900° F.

Drawing or tempering is usually done with the oxyacetylene torch as the above technique is used only on small repairs. The drawing or tempering operation relieves contracting stresses set up by the cooling of the weld deposit.

Temperature indicating materials are again recommended to control the degrees of heat for tempering. If they are not available, it is best to watch the color range in the base metal.

Light straw, 400° F.
Dark straw, 475° F.
Copper, 520° F.

Purple, 550° F.
Light blue, 640° F.
Red in dark room 900° F.

It is advisable to pack the die or tool adjacent to the area of the weld deposit with a plastic-asbestos compound to prevent annealing or slight surface decarburization.

In a salvage repair of this type, it is not wise to make repair that is greater than $^3/_8$ in. in depth. If the break is larger than this, the normal arc welding procedure is recommended, using the cushion method of repair.

In all cases the part being welded must not be exposed to draughts of air as this would cause checking and cracking of the weld deposit. It is obvious that time and money can be saved by this type of reclamation.

Figure 3 shows three typical examples of tool repair: A reamer, a drill and a slab cutter, showing the damaged areas. All have sharp cutting edges, any prolonged heating would anneal the adjacent cutting edges.

Figures 4 shows the three tools after they have been built up and cooled.

Figure 5 shows the three tools after they have been drawn or tempered and they have been ground to their finished size, ready for further use.

Figure 6 illustrates an oil-treated steel punch, showing the three stages, before build-up, as it had been built up and cooled and the punch tempered, ground and ready for further service.

Another technique that was perfected was due to the recent development of the new chamfering and gouging electrode, the oxygenless metal removing electrode. A new phase of die welding was investigated, particularly repairs made on large cast-iron dies.

Figure 7 shows a welder using the chamfering and gouging electrode, it is a "welding rod in reverse"—features a heavy coating which forms a cone at the striking end of the electrode. As a result, you get a natural jet-effect arc, creating an intensely concentrated source of heat which swiftly and easily removes unwanted metal of all types for all chamfering grooving.

Cast-iron dies are usually large and massive. They

Fig. 3 Typical tools which can be repaired by build-up; illustration shows a reamer, a slab cutter and a drill before repair

Fig. 4 The same tools after build-up and cooling. Prolonged heat which would have annealed their cutting edges has been avoided

Fig. 5 The three tools of Figs. 3 and 4 after drawing, tempering and grinding to size. Tools are now ready for use

Fig. 6 An oil-treated steel punch (from left to right) before build-up, after build-up and cooling, and after grinding to size ready for service

Fig. 7 Welder gouging and chamfering swiftly and easily grooves all types of metal

are used for stamping and forming sheet metal parts as used in the automotive and farm implements industry.

These large cast-iron draw dies have been built up and welded for some time with nickel-base electrodes, but it has not been entirely satisfactory because many times the weld overlay or buildup has had a tendency to peel or break away from the base metal.

This peeling is generally caused by one of two things. The relatively porous die surface becomes impregnated with the various oils or solutions that coat steel sheets. The oil, during the welding operation forms hydrogen which prevents a good bond to the base metal. Usually the bonding pass is so full of porosity that it has little tensile strength and very low ductility.

In addition, under continuous use, the surface work hardens and becomes brittle. Therefore, a build-up or repair on a brittle surface, where the weld as it is deposited would contract during cooling, considerable underbead cracking is likely to result. Otherwise, the brittle surface may be so highly stressed that in a relatively short time the overlay would break away, taking a certain amount of the brittle surface with it.

In the past, whenever it was practical, the area was studded, in that holes were drilled and tapped, ordinary machine bolts were screwed in and cut off just above the surface of the cast-iron die. This was generally not satisfactory because everything depends on a mechanical joint. Often the bolts would shear off or the bolts would stretch at the first thread, resulting in a failure of the overlay or build up.

With the development of chamfering electrode, field tests were made to see if better results could be had and the die life extended. By gouging grooves in the area and filling in the grooves as well as the build-up with solid weld metal, a better bond was made than the old studding process.

Different designs of grooving were tried. The best results obtained are illustrated in Fig. 8. The recommended procedure is to take a piece of chalk and outline the area to be built up, take gouging electrode and gouge a groove $^1/_2$ in. inside the chalk mark. Then gouge two more grooves; one directly across the center of the area to be built up, the other gouged at right angles to the groove just cut, so as to make a letter X. If the surface of the die is badly checked it is advisable to gouge additional grooves.

No preheat is necessary before gouging the grooves in the die. Gouging electrodes $^1/_8$ and $^5/_{32}$ in. in diam are recommended, using a direct-current welding machine, straight polarity, with 300 amp for the $^1/_8$-in. electrode and 350 amp for the $^5/_{32}$-in. electrode.

After gouging, use the low-watt input electrode specially developed for cast iron and weld the grooves first, peen the welds as each pass is applied. When the grooves have been filled, proceed with the overlay.

Gouging has the following advantages. There is a bond into solid base metal. There are no sharp corners to start a root crack. Moreover, the special coating formulation on the ChamferTrode electrode prevents contamination of the base metal, as carbon

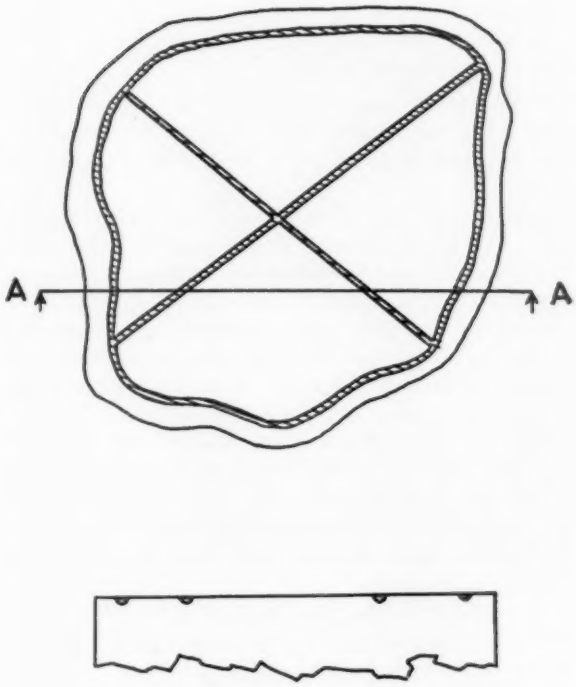


Fig. 8 Recommended design for grooving tool steel preparatory to build-up

pickup, etc. The groove that has been filled with weld metal is a definite anchor, an area where no oil has penetrated nor is any brittleness evident. The groove is solid weld metal and nothing depends on a mechanical bond, no strength is lost due to drilling and tapping. No impact will be great enough to break the "anchors" out of the die.

The anchoring or grooving technique lends itself to a greater use of hard overlays on cast-iron dies. Formerly due to the contraction of hard overlays during cooling, the bond would be broken in a relatively short time. As a result the only build-up rod used was the specially developed low-watt input electrode for cast iron which had a Brinell hardness of 180 to 240. In some cases this was too soft for deep draw operations. Thus, wherever hard overlays are to be used the special low-watt input electrode for cast iron is used only for the initial pass or cushion layer. The anchor or groove filled with the cushion layer will take up the contraction of the subsequent layer of overlay material, minimizing the effect of the pulling or shrinking action.

Two of the work-hardening electrodes have given excellent results where after machining is a prime requisite. One is the special low-watt input nickel-and-chrome type. The other is the special low-watt input nickel-manganese type of electrode.

If a greater hardness is required, then it is recommended that the special low-watt input tool steel electrodes, such as oil-hardening or air-hardening types, employed on steel dies be used. Peening between each

Fig. 9 Large mild steel electrode (E6010) used to produce a machinable deposit with another E6010 electrode used as auxiliary filler to obtain a rapid build-up

pass as outlined for steel die welding is also recommended.

In the survey mentioned in the first part of this paper, tool room superintendents indicated a desire for a tool steel electrode that left a machinable deposit. This was next to an impossibility with conventional electrodes as each desired different Rockwell hardnesses. It is impossible to procure electrodes with core metal with such slight variations in hardnesses (one or two points Rockwell); furthermore, the welder has much to do with various deviations, higher welding amperages will result in greater base metal dilution, etc.

However, considerable thought was given to this question and tests were made using an old welding technique employed in everyday work for welding and bridging gaps in poor fit-up work.

I refer to the technique of using a large mild steel electrode such as E6010 in the electrode holder in the conventional manner but using 20 to 25% greater amperages. To make a fast build-up another E6010 electrode was fed into the arc which was consumed as an auxiliary filler rod. The excess amperage melts down the auxiliary filler rod. Figure 9 shows the position of the electrodes in the above described technique.

Using this method two different types of electrodes can be employed to change the metallurgy of the weld deposit. Tests were made by using a special low-watt input tool steel electrode such as the air-hardening or high-speed steel types as the electrode that is placed in the electrode holder. The size of the electrode used would only be governed by the size of the overlay to be made.

The auxiliary filler rod used as a special low-watt input chrome-nickel (austenitic type) electrode, is one

Fig. 10 The auxiliary electrode being fed into the arc stream

size smaller than the tool steel electrode used in the electrode holder.

If the auxiliary electrode were not held in the welding arc the weld deposit would naturally show an uneven deposition and excessive puddling of the base metal due to the higher amperages used with the electrode in the electrode holder.

When the auxiliary low-watt input electrode is moved in accordance to deposition rate of the overcharged tool steel electrode the higher amperage merely melts down the low-watt input chrome-nickel filler electrode.

Figure 10 shows a welder making a machinable deposit.

To change the Rockwell hardness of the weld deposit it is only necessary to change the diameter size of any of the electrodes used; for example, if a lower Rockwell deposit is desired, use the same diameter size auxiliary filler electrode as the electrode used in the electrode holder, or use the low-watt input chrome-nickel electrode in the electrode holder and use the low-watt input tool steel electrode as the auxiliary filler rod.

The special low-watt input electrode used in the electrode holder and the low-watt input filler electrode mix together thoroughly and at no time does either coating form slag inclusions in the weld deposits. If slag inclusions are evident, it is an indication the welding amperages are too low.

It will be necessary to experiment with several combinations to find the desired Rockwell hardness in the weld deposit. Field tests have proved to be very successful on forging and deep draw dies. Cutting edges on a shear die require greater skill and careful manipulation of the auxiliary low-watt input filler electrode.

High-Speed Motion Picture Photography Applied to Resistance Welding

High-speed motion pictures of some resistance welding applications to small welds

by I. S. Goodman

Synopsis

Recent developments in high-speed motion picture photography have permitted taking pictures at 1000 to 10,000 frames per second. This technique has previously been applied to arc welding applications, but there is little published evidence of its application to resistance welding. Some investigations are described and illustrated wherein high-speed photographic methods show promise of resistance welding application. These include follow-up on small bench welding heads, high-speed butt welding of small diameter wires, percussive welding and vibration phenomena as applied to small welds. Black and white motion pictures will be shown that suggest how this equipment and technique may be further applied.

BACKGROUND OF HIGH-SPEED PHOTOGRAPHY

THE use of high-speed photography in welding applications is not new. However, it would appear that the acknowledged work thus far has been entirely in the field of arc welding. The purpose of this paper is to suggest possible applications to resistance welding methods and to testing of welded assemblies.

Before embarking on this course, it might be well to review briefly the development of this photographic process. High-speed photography was born about 1872 and is generally credited to Muybridge. About that time, Governor Stanford of California was interested in determining whether, at any stages of a galloping horse's movement, all four feet were off the ground, to settle a wager. His friend, Muybridge, set up a number of adjacent cameras so triggered that a passing horse would trip the shutters successively, providing a series of instantaneous exposures, fractions of a second apart. The system was successful and provided the necessary evidence. In France, about this time, Marey developed what was substantially the same system with the additions of a stroboscopic disk which permitted the motion to be reconstituted.

From 1890 to 1930, progress was slow but gradual. Improvements were more along the lines of faster lens and film emulsions than mechanical techniques. During this period also, the spark method came into extensive use for ballistic studies. However, when the gaseous discharge tube appeared and was applied by Edgerton with wide publicity, the great applicability of high speed techniques to many industrial problems became evident.

All the above applies essentially to still photography. Although motion picture cameras date back to the beginning of this century, in conventional cameras, the film stops, the shutter opens, the film is exposed, the shutter closed and the film moved to the next frame. This sequence occurs at 16 cycles (frames) per second with 8- and 16-mm film, and at 24 frames with commercial 35-mm cameras. These cameras can usually also be operated at higher speeds, but mechanical failure in the camera mechanism occurs at frame speeds above 150 per second.

Within the past 15 years only, have commercial cameras appeared using basically different principles which allow film speeds up to 10,000 frames per second. These cameras do not use a shutter at all but a rotating prism and continuously moving film.

The prism is rotated in synchronism with the film

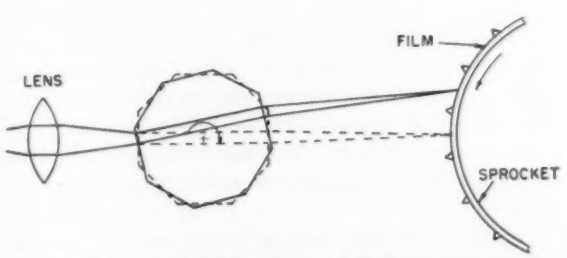


Fig. 1 Schematic high-speed motion picture camera

I. S. Goodman is with the Lamp Division of Westinghouse Electric Corp., Bloomfield, N. J.

Presented at the AWS Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19-23, 1953.

creating successive and properly spaced images traveling with the film. Figure 1 is a schematic of the system. The image gathered by the lens is refracted by the prism upward to meet the incoming frame, and as the frame advances downward, the image follows, thereby permitting continued exposure throughout the period that the film passes the aperture.

Naturally, at these speeds, considerable light is necessary, but our subjects were sufficiently luminous or could be sufficiently illuminated to permit reasonable lens apertures. Unfortunately, as is true of many high-speed pictures, the problems to be described can be illustrated best by the projection of the actual films as will be done when this paper is presented; it is hoped that the reader will obtain some value from the frame enlargements accompanying this text.

The two cameras of this type currently commercially available are the Wollensak Fastax (originally developed by Western Electric) and the Eastman Kodak High Speed Motion Picture Camera. Cameras are available in 8-, 16- or 35-mm models; and at speeds up to 14,000 frames/sec. Each of the models has its advantages and adherents, and this writer will not attempt to prejudge them. Cameras utilizing strobo-

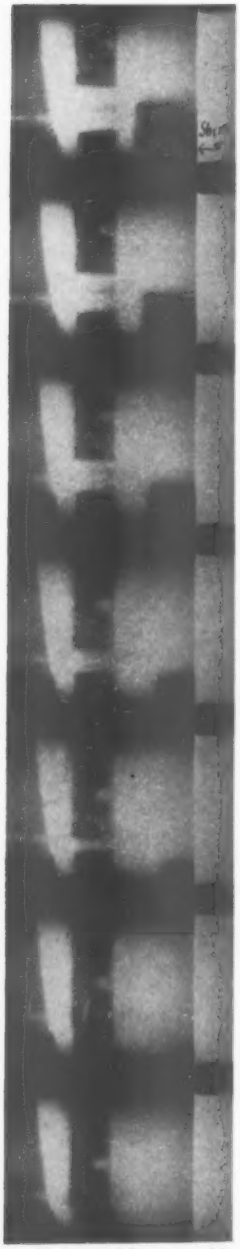


Fig. 2 Enlarged frames of bench welder closing sequence

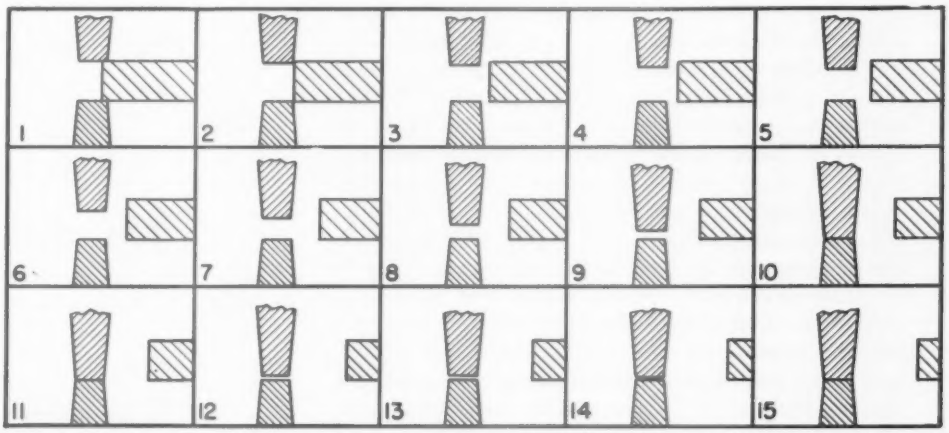


Fig. 3 Bench welder "follow-up" sequence reconstituted by drawings (1320 frames/second)

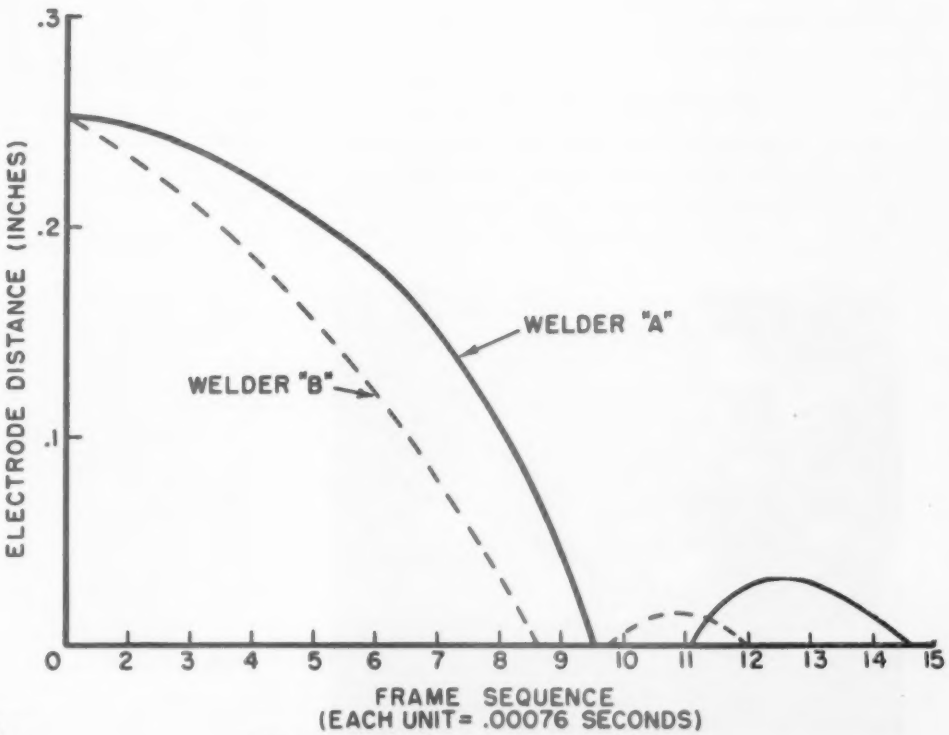


Fig. 4 Variations in bench welder "follow-up"

scopic lights continue to have some uses but are more cumbersome than the above and are not adaptable to self-luminous objects such as arcs.

FOLLOW-UP ON BENCH WELDERS

In previous papers before the AWS, the writer and others have emphasized the need for extremely low inertia in small bench welder heads. As welding times have become increasingly shorter through the use of condenser discharge and phase shifted half-cycle firing, fast follow-up assumes great importance. One of the methods we have used to compare relative performance involves the following procedure:

A shim of suitable thickness (in this case 1/4 in.) is inserted between the electrodes (1/4 in. diameter) of the welder which is in turn locked at 8 lb pressure. The shim is rapidly retracted and the electrodes are permitted to close upon each other. Meanwhile the whole action is being photographed at 1320 frames/sec. Figure 2 shows seven frames from such a sequence. When the motion picture frames are projected individually, accurate measurements can be taken which permit the reconstitution of the action in drawings as in Fig. 3 or graphs as in Fig. 4. It will be seen from Fig. 4, that welder "A" took 0.01 second (longer than 1/2 cycle of 60-cycle current) to close and remain closed. There was also a bounce which is not perceptible to normal vision. Welder "B" under similar conditions has a shorter closing time and less bounce from which we infer it also has less inertia and better dampening. We expect to use similar motion pictures of other welding heads to help determine the best design to match various welding timers.

LEAD WIRE WELDING

Every incandescent lamp made has at least two lead wires; radio tubes have many leads. These leads consist of two or more materials in wire form butt welded together. A typical lamp lead may consist of 61 mm of 0.016-in. nickel-plated copper, welded to 3 mm of 0.016-in. dumet (copper-coated nickel-iron), welded to 50 mm of 0.016-in. copper. These are fabricated at speeds of about 200 leads (400 welds) per minute on a welding machine similar to Fig. 5. At operating speed it is not possible to measure the many variables that go into a quality weld and shrinkage-free manufacture. Some of these variables are alignment, initial spacing, weld arc, machine vibration, etc. However, as will be shown, high-speed motion pictures permit the measurement of these variables.

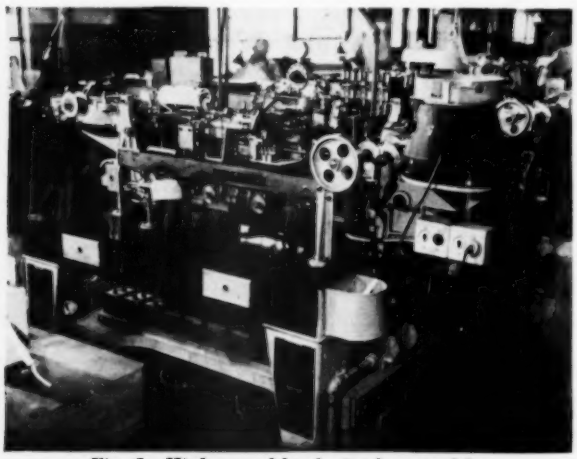


Fig. 5 High-speed lead wire butt welder

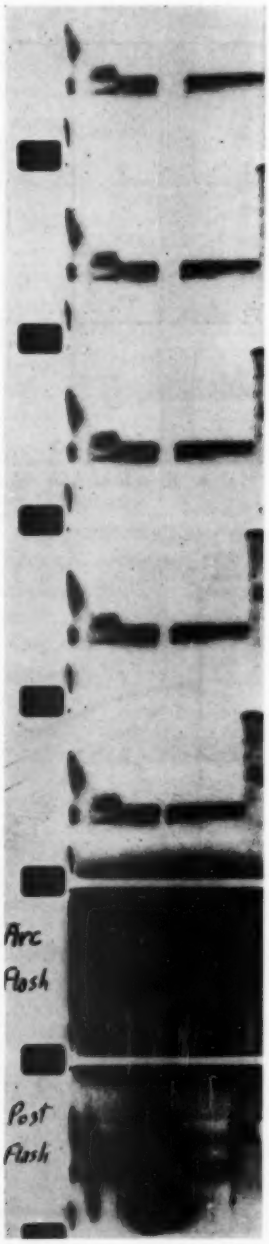


Fig. 6 Enlargements of frames of percussive welding sequence (10,000 frames/sec). (Negative prints)

Fig. 7 Automobile lamp under impact test (2200 frames/sec). (Negative print)

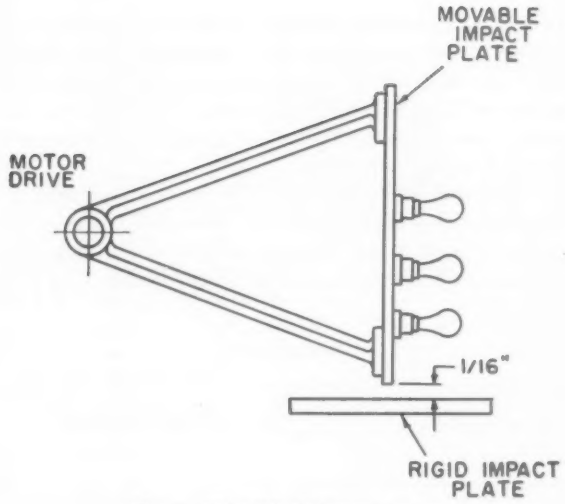


Fig. 8 Simplified impact tester

PERCUSSIVE WELDING

Many types of percussive welds are described in the literature and patent art. These involve various voltages, currents, methods of electrical discharge and associated mechanical electrode devices. High-speed photography offers a potent analytical tool in this field. Figure 6 shows a sequence of frames from a film taken at 10,000 frames/sec in which the moving electrode attains a speed of over 100 ft/sec before percussion.

VIBRATION AND FATIGUE TESTING

Another application that will be used to illustrate in some detail the unique use of high-speed motion picture photography to testing applications is concerned with impact and vibration testing, where there is much need for improved methods of analysis today. Many lamps, especially household types, are burned in fixed positions; other lamps, particularly those on moving vehicles and naval ships and aircraft, are subject to considerable shock and vibration.

This is very hard on the incandescent filament which is in suspension between relatively rigid support members. Very often questions arise as to whether we should clamp or weld the filament and where to weld and by what welding method. In order to answer these questions, we should like to know more about the movements of this filament, as to its whole and as to its individual turns, under impact and vibration. These movements are of too small an amplitude and too frequent to be measured by an observer. One such impact tester is illustrated in Fig. 8. It consists of a vertical plate on whose surface is rigidly mounted a number of suitable sockets having electrical connections for burning lamps in a horizontal position. This vertical plate may be impacted, cantilever fashion, against a rigidly mounted horizontal plate; some control of frequency and amplitude of impact is possible. This type of tester is extensively used for automobile

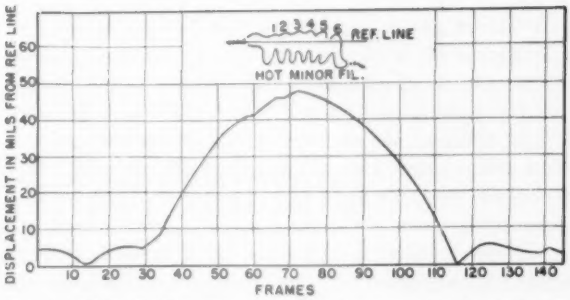


Fig. 9 Coil displacement during impact test (see Fig. 7)

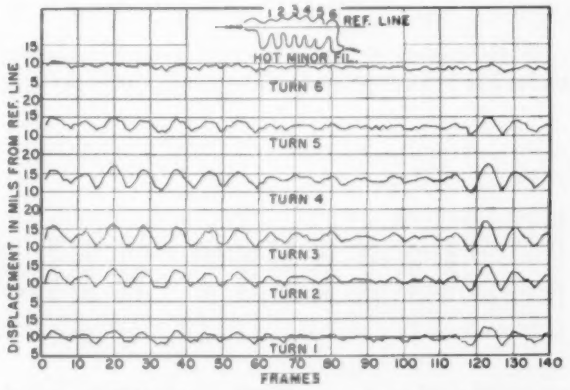


Fig. 10 Individual turns displacements during impact test (see Fig. 7)

headlights. Figure 7 shows four enlargements of 16-mm frames from a motion picture of an automobile lamp being impact tested. The pictures were taken at 2200 frames/sec; the frequency of impact was 16 cps; thus, one cycle of impact was spread over 140 frames. The four frames shown were taken from different positions of one such cycle. One filament is burning at rated voltage; the other is cold as would be normal with such lamps.

A close inspection of these photographs will show varying positions of the turns with respect to each other during the course of one cycling. The whole coil also moves, of course, as can be seen with respect to the fixed line on the frame. By projecting each frame of the 140 total onto a screen, precise measurements can be made which lead to the reconstructed visualizations in Figs. 9 and 10.

Figure 9 shows the displacement of a fixed reference line during one cycle, this reference line being arbitrarily drawn to coincide with one of the rigidly clamped filament legs. It can be seen that the displacement of the entire coil during one cycle is approximately 0.050 in. and that the plates bounce slightly on impact.

Figure 10 shows the vertical displacement of each of the individual turns with respect to the same reference line during one cycle. Since Figs. 9 and 10 have the same horizontal time axis, they may be superimposed for easier analysis. One can observe that, during one impact cycle, the individual turns vibrate with varying amplitudes and varying frequencies of oscillation. The center turns vibrate with greater amplitude and lower frequency than do the outside turns.

A similar graph can be made of the horizontal displacements of the turns with respect to one another. Other sets of graphs obtained by this same method can be made using different test conditions, different lamps, different test equipment and all these contribute data which permits us to predict quality design. This technique lends itself readily to testing of other welded assemblies, even to catching in very slow motion, the actual mechanism at the moment of failure of specimens under tensile, vibration, corrosion or fatigue test.

CONCLUSION

A brief history of high-speed motion picture photography has been presented. The ability to apply this technique to several different resistance welding and testing problems has been demonstrated. It is hoped that this will prove stimulating to the thoughts of others working on similar problems. We feel that the proper use of this equipment will provide a potent tool for product improvement.

Acknowledgment is made of valuable assistance in the preparation of this paper by various engineers of the Lamp Division of the Westinghouse Electric Corp., and particularly to Jack Martin for Figs. 9 and 10.

References

1. "High Speed Photography, Volume I," *Jnl. Soc. Mot. Pict. Engrs.* (March 1949).
2. "High Speed Photography, Volume II," *Ibid.* (November 1949).
3. *High Speed Photography*, John Wiley & Sons, New York, 1952.

CURRENT WELDING LITERATURE

Accident Prevention. Apparatus for Protection Against Dangerous Voltages in Welding Equipment, F. H. de Jong and D. W. van Rheenen. Philips Tech. Rev., vol. 15, no. 7 (Jan. 1954), pp. 199–204.

Accident Prevention. How to Guard Against Toxic Welding Fumes, W. Schweisheimer. Can. Machy., vol. 65, no. 2 (Feb. 1954), pp. 168, 214, 216.

Aircraft Engine Manufacture. Production of Aft Frames for Aircraft Gas Turbines, L. M. Limbach. Machy. (Lond.), vol. 84, no. 2151 (Feb. 5, 1954), pp. 273–278.

Aircraft Manufacture. Modern Welding of Aircraft Components, W. P. Brotherton. Steel Processing, vol. 40, no. 2 (Feb. 1954), pp. 92–96, 115.

Automobile Manufacture. Automatic Welding Lines for Fisher Body Components, T. MacNew. Automotive Industries, vol. 110, no. 1 (Jan. 1, 1954), pp. 56–59.

Automobile Manufacture. Wide Application of Automation to Welding, P. Kennedy. Automotive Industries, vol. 110, no. 4 (Feb. 15, 1954), pp. 44–49, 176.

Chemical Equipment. Welding in Atomic Energy Projects, I. H. Hogg. Welding & Metal Fabrication, vol. 22, no. 1 (Jan. 1954), pp. 2–14.

Containers, Manufacture. Use of Solder Paint in Container Manufacture, G. Taylor. Sheet Metal Industries, vol. 31, no. 322 (Feb. 1954), pp. 123–124, 128.

Fasteners. Fastening and Joining. Product Eng.—Annual Handbook of Product Design for 1954, p. G-3-G38.

Hydroelectric Power Plants. Welding Operations in Hydro-Electric Plant, A. N. G. Bray. Australasian Engr., vol. 46 (Jan. 1954), pp. 52–57.

Inert Gas. Self-Adjusting Arc—Improved Power Sources Use Low Voltages, J. C. Needham, W. G. Hull and L. H. Orton. Can. Machy., vol. 65, no. 2 (Feb. 1954), pp. 164, 166, 190.

Light Metals. High-Speed Mill Forms, Induction Welds and Sizes Thin-Gage Nonferrous Tubing, T. J. Crawford. Metal Progress, vol. 65, no. 2 (Feb. 1954), pp. 65–70.

Light Metals. 6 Processes for Fusion Welding of Aluminum, L. F. Spencer. Welding Engr., vol. 39, no. 2 (Feb. 1954), pp. 58–62, 64, 66.

Oxygen Cutting. Uniform Powder Flow Gives Better Cuts in Stainless, J. R. Kirwin and J. Holmstock. Iron Age, vol. 173, no. 9 (Mar. 4, 1954), pp. 156–157.

Oxygen Cutting Machines. Development of Oxygen Cutting Machines, L. J. Hancock. Welding & Metal Fabrication, vol. 22, no. 2 (Feb. 1954), pp. 59–63.

Penstocks, Welded Steel. Automatic Field Welding 14-Foot Penstock Sections, G. M. Mills. Can. Machy, vol. 65, no. 2 (Feb. 1954), pp. 153–154, 160.

Pipe Lines. Non-Destructive Tests of Field Welds on Welded Pipe Lines, J. H. Lawson. Australasian Engr., vol. 46 (Jan. 1954), pp. 57–60.

Soldering Aluminum. Ultrasonic Soldering and Tinning, A. E. Williams. Can. Machy., vol. 65, no. 1 (Jan. 1954), pp. 137–140.

Soldering. Technique of Soldering to Thin Metal Films, R. B. Belser. Rev. Sci. Instruments, vol. 25, no. 2 (Feb. 1954), pp. 180–183.

Steel Weldability. Effect of Steel Quality on Spot-Welding Properties, J. E. Roberts and H. E. Dixon. Brit. Welding J., vol. 1, no. 1 (Jan. 1954), pp. 27–35.

Steel, Weldability. Vanadium as Replacement for Molybdenum in Low-Alloy Steels, C. L. M. Cottrell and B. J. Bradstreet. Brit. Welding J., vol. 1, no. 2 (Feb. 1954), pp. 82–86.

Titanium Welding . . . In Tank. Steel, vol. 134, no. 9 (Mar. 1, 1954), pp. 114–115.

Tubes. Aluminum Tubing and Pipe. Modern Metals, vol. 9, no. 12 (Jan. 1954), pp. 46, 48–49.

Water Tanks and Towers. Standpipe Moved 50 Miles, T. B. Jefferson. Welding Engr., vol. 39, no. 2 (Feb. 1954), pp. 48–49, 53.

Welded Steel Structures. Design and Construction of Welded Portal Frame Warehouse Building Designed by Plastic Method, E. J. Callard. Structural Engr., vol. 32, no. 1 (Jan. 1954), pp. 30–37.

Welded Steel Structures. Welded Structure in Pump-House Foundation, H. Smith. Brit. Welding J., vol. 1, no. 1 (Jan. 1954), pp. 13–25.

Welded Steel Structures, Stresses. "Grass Roots" of Stress Control, J. Holt. Welding Engr., vol. 39, no. 2 (Feb. 1954), pp. 50–53.

Welding. Aluminum Alloy and Stainless Steel Fabrication. Welding & Metal Fabrication, vol. 22, no. 2 (Feb. 1954), pp. 46–51.

Welding, Electric Arc. Development of Metal-Arc Welding and Electrodes During Past Half-Century, E. Flintham. Brit. Welding J., vol. 1, no. 1 (Jan. 1954), pp. 3–10.

Welding, Electric Arc. Self-adjusting Arc and Controlled Arc Welding Processes, W. G. Hull and J. C. Needham. Iron & Coal Trades Rev., vol. 167, no. 4472 (Dec. 25, 1953), pp. 1473–1475.

Welding, Electric Arc. Twin-Arc Welding Process, W. D. Waller. Sheet Metal Industries, vol. 31, no. 322 (Feb. 1954), pp. 131–135.

Welding, Electric Arc. Welding with Magnetic Flux, R. A. Hand. Welding Engr., vol. 39, no. 2 (Feb. 1954), pp. 57, 84.

Welding Machines Control. Air and Oil Circuits Are Combined for Resistance Welders, L. R. Conklin. Applied Hydraulics, vol. 7, no. 2 (Feb. 1954), pp. 33–36.

Welding. Structures for Atomic Defence. Welding & Metal Fabrication, vol. 22, no. 1 (Jan. 1954), pp. 22–27.

Welds. Distortion Can Be Designed Out of Welded Structures, J. R. Stitt. Steel, vol. 134, no. 10 (Mar. 8, 1954), pp. 120–122.

Welds, X-Ray Analysis. Radiographic Examination of Welding, E. J. Barnard. New Zealand Eng., vol. 8, no. 12 (Dec. 1953), pp. 420–432.

Process Adjustment in Inert-Gas-Shielded Arc Welding

Factors involved in successful fabrication of weldments by the inert-gas-shielded arc-welding process and their statistical control

by Eugene B. LaVelle

Synopsis

It is possible to obtain statistical control of welding when applying the inert-gas-shielded welding process if the factors relating to process adjustment are properly considered. A list of questions for use in analyzing the specific application of the process is presented. Relative information follows each question as it appears.

The inert-gas-shielded arc-welding process has suffered because of failure to consider the factors involved in successful fabrication of weldments with this process. It is essential that individuals on all levels of welding responsibility become more familiar with the details of the process so that its application may be successfully predicted and fully realized.

INTRODUCTION

THERE are probably more widespread beliefs, ideas, notions, opinions, prejudices and feelings connected with the application of this welding process than with any other of which we know.

If the interest of individuals in departments other than that of fabrication could be extended toward learning more about the practical aspects of the process, there would be greater possibility of attaining a more profitable application.

A large gap exists between engineering and fabrication personnel concerned with the application of the welding process. The writer has chosen to organize the material under headings which apply specifically to the process itself, rather than according to the functional responsibility of the various departments of the industrial concern. It was believed that this form would permit all classes of personnel to view the process more objectively.

The scope of this paper is such that the treatment is general in nature and specific only to the extent that the approach to making justifiable decisions will be guided. Only the more important considerations are covered in order that voluminous details will be avoided.

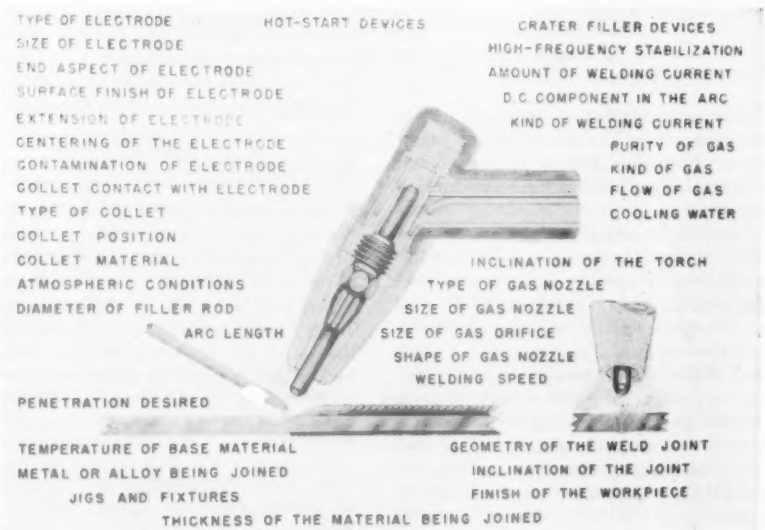


Fig. 1 Interrelated factors in process adjustment for inert-gas-shielded tungsten arc welding

However, it is necessary to obtain enough background of knowledge, experience and technical information so that data relative to the specific application at hand can be properly analyzed and interpreted.

A famous surgeon once said, "Survey, analyze, and recommend." This procedure is as applicable to welding as a joining process as it is to the practice of medicine. Scientific procedure must be founded upon organized knowledge and the success of any welding operation depends upon following the proper procedure. This is one of the landmarks of the industry, but there is a tendency when new welding processes are presented to the Welding Trade to give too much recognition to individual skill and ability in applying them without determining priorly what controls must be used to reduce the requirement for a high degree of operator skill.

If economic and quality control is to be established, the various process factors must be considered in detail. If this is done and each application considered on this basis, it will be easy to establish statistical control of welding. The inert-gas-shielded arc-welding process has suffered widely because of failure to do this.

The welding process chosen for any particular application should be the one best suited to meet the economic and metallurgical requirements. Inert-gas-shielded arc-welding measures up well with other welding processes in these respects. The general features of the process are well known. However, it is essential that the details of the procedure be considered if application analysis is to be made possible.

APPLICATION ANALYSIS

The Magic Formula

In connection with the proper applica-

Eugene B. LaVelle is Principal Welding Engineer for the Engineering Department, General Electric Co., Hanford Atomic Products Operation, Richland, Wash.

Presented at the National Spring Meeting, AWS, held in Buffalo, N. Y., May 4-7, 1954.

tion of any welding process, it is good practice to use what has been called "The Magic Formula." (Author unknown.) This consists of four simple questions a person may ask himself:

1. What am I trying to *do*?
2. What do I *know* about it?
3. What can I *do* about it?
4. What are the *probable* or *possible* outcomes?

Very often if a person takes time to formulate the problem, the solution will come quickly to mind. By the time the second or third question has been considered, it is rare that a solution has not been reached. Most difficulties arising from the application of inert-gas-shielded arc welding come from people using it without actually thinking to any extent about the practical considerations.

Technical Data

The accumulation of data and its arrangement into a usable reference file is essential in order that a fabricator may enter the general field of inert-gas-shielded arc welding. It is comparatively simple to organize for a single operation and do so successfully. However, to encompass the whole field of inert-gas-shielded arc welding requires that as much experience and knowledge be brought to bear as is obtainable through available literature. A great deal of effort must be extended to attain this objective. Without a basis of prior knowledge, special welding techniques and procedures can be developed only at considerable expense and effort. When developing a new procedure, complete records must be maintained during the course of the experimental work. There are so many variables involved that it often becomes difficult to reconcile such fundamental factors as gas flows, amperage values, arc lengths, torch inclination etc., on the basis of observed results unless, periodically, stock is taken of the records that have been maintained.

INTERRELATED FACTORS IN PROCESS ADJUSTMENT

In this paper, "interrelated factors" is a term applied to all the items which must be considered when setting up for an efficient welding operation with this process. The influence of any one factor upon the others varies from the degree of extremely important to relatively meager significance.

It is not generally understood how interrelated and important are the various factors in the adjustment of welding conditions inherent to this process. More recognition should be given to the important bearing which many of these have on successful process application. About thirty-eight different important factors govern the practical use of this process. There are others but those appearing on the accompanying illustrations are the most important. A proper understanding of the nature of these factors and how to control them is essential to any fabricator who uses this process. It is repeated, that as each new application is approached, it is necessary to maintain adequate records of experimental work so that duplication of effort will be avoided. Past experience with the process should be analyzed so that such knowledge can be used toward making a positive approach to future welding problems.

The following information has been arranged in numbered question-and-answer form with the thought in mind that the questions themselves might be used as the basis for formulating an application analysis sheet that could be adapted to the needs of any individual fabricator. Only such items might be withdrawn as would be applicable to his own particular operation. Arrangement under each general heading is in order of relative importance.

Health and Safety

Before developing the process application data, the fabricator must be assured that all reasonable consideration has been given to the health and safety of his personnel and protection of the equipment. The following coverage is brief, but outlines the primary considerations with regard to this phase of the operation.

Personnel

1. What precautions must be taken to protect personnel against radiation? Radiation is to be expected and the eyes and skin must be protected by suitable means to withstand the rays emitted by the arc. When welding with this process, a filter lens which has a thin transparent layer of metal on the arc side of the lens has been found very effective. For welding with amperage lower than about 90 amp, it is ordinarily unnecessary for most operators to use leather protection for the hands. However, for normal welding heats, thin leather gloves with short cuffs should be worn. For welding with very heavy currents, more effective protection against the radiated heat may be required. Some applications on heavy material require the use of asbestos gloves and air supply into the operator's hood and clothing.

2. What precautions must be taken to protect personnel against high voltage? It is good practice to have the operator stand on an insulating material, or be otherwise protected against accidental shock. It is an unsafe practice to touch the electrode or any part of the current-carrying equipment should high-frequency stabilization be used. Contact of the skin with the electrode carrying high-frequency current may also cause small burns which will heal slowly and, if the skin is moist, may result in some pain.

3. What precautions must be taken to protect personnel against toxic gases? A hazard peculiar to the inert-gas-shielded welding processes is the large emission of ozone, a form of oxygen extremely irritating to the respiratory system which causes inflammation of the respiratory tract if too much is inhaled. Ozone is noticeable because of its sharp, biting acrid odor. This is particularly objectionable when welding on certain aluminum jobs, when the oxide is thicker than ordinarily would be the case.

The possibility of dangerous radioactivity has been exhaustively investigated and the Atomic Energy Commission has removed its resistance to use of the thoriated tungsten electrodes as a result of this study.

Danger exists from the inhaling of argon or helium, if the proportion of inert atmosphere inhaled becomes so large as to interfere with the operator's normal oxygen requirements. The condition known as anoxia (oxygen starvation) then occurs and the operator is in danger of smothering if the condition persists over too long a period.

Introduction of an argon or helium atmosphere into a container will gradually displace the breathable atmosphere. When this condition arises, the operator working in the container should secure his breathing air from a source outside the container in which he is welding or exhaust the inert atmosphere from the container by means of an air syphon. In the case of helium, which is lighter than air, the intake should be placed at or near the top of the container and if argon is being used, which is slightly heavier than air, the intake should be near the bottom.

The potential hazard existing when materials are welded which emit toxic fumes should not be overlooked. The most common metal vapors which may be encountered are those emitted by lead, cadmium, beryllium, zinc and copper. Fluorine-bearing fluxes emit toxic fumes when heated and adequate exhaust devices must be used. Also if a hydrocarbon, such as carbon tetrachloride, trichlorethylene, etc., is used to degrease the work, the fluid should be permitted to evaporate or be wiped from the work before the welding operation is started. Arc welding should never be done in any location near fumes of these solvents as they will dissociate in the light of the arc to form a poisonous gas, phosgene.

Process Equipment

1. What precautions must be taken to protect process equipment against excessive heat?

Plastic hoses should be protected and supported in such a manner that their contact with hot materials is virtually

impossible. Fusing devices in the apparatus power cable will provide adequate protection against excessive heat build-up in the system. One method of insuring constant water flow for cooling is to provide that the water discharge be within vision of the operator. Another is to provide a power circuit breaker which would operate if the water supply should fail. Consideration should be given to the amperage to be used for the specific application when choosing gas nozzles. If ceramic gas nozzles are operated too near their upper limit, the deterioration will be much more rapid than if the nozzle were chosen for size which would operate near its medium heat range.

2. What precautions must be taken to protect water-cooled process equipment against freezing?

For inert-gas-shielded systems requiring the use of water for cooling purposes, the possibility of water freezing within the apparatus must be avoided. A single "freeze" may damage various sections of the apparatus beyond repair. If the temperature of the welding location falls below freezing, certain protection against such an occurrence is to completely drain the system during the hours it is not in use. If a recirculating water system is used for cooling, an antifreeze compound may be used in the water to prevent freezing.

3. What precautions must be taken to protect water-cooled process equipment against excessive water pressure?

In water-cooled systems, excessive pressures may damage the apparatus. If plant service is to be used, a pressure regulator should be installed between the source and the apparatus. All water-cooled welding apparatus carries with it the manufacturer's recommendation as to water pressures.

4. What precautions must be taken to protect water-cooled process equipment against contamination?

Contamination of the apparatus with sand, gravel or other foreign material becomes possible if the system is not adequately screened against their intrusion. If this occurs with some makes of torches, it is necessary to completely dissemble the torch or clogged element of the system, a time-consuming and costly process.

Electrical Factors

1. What kind of welding current or current polarity should be used for the metal or alloy to be welded?

Fundamentally, there are but three choices of welding currents: (1) direct current, straight polarity, (2) direct current, reverse polarity and (3) alternating current. Certain desirable effects can be obtained by superimposing high frequency on the other welding currents. Alternating current may be represented as a series of current pulses of alternate, direct current straight polarity and direct current reverse polarity, having some of the desirable characteristics of each. It gives good penetration and surface oxide reduction, and the form of the bead is more nearly that of the ideal metal arc deposit with slightly less reinforcement. The bead is wider than direct current straight polarity, but narrower than direct current reverse polarity. It is deeper than direct current reverse polarity, but shallower than direct current straight polarity. Alternating current is best for the welding of aluminum, magnesium and beryllium-copper, although direct current reverse polarity has been used for welding thin aluminum and magnesium. Alternating current should be used when it is necessary to weld the thinner gages of material as direct current straight polarity gives very deep penetration with a narrow bead. Welding with direct current reverse polarity requires great skill and is not generally recommended because of the large size of electrode which must be used with a comparatively low level of welding current. Aluminum is particularly difficult to weld with this type of current, as the weld puddle appears to be attracted to the electrode tip, contaminating it badly when touched. This type of current for unit value of welding current has the coldest effective arc of the three, but does give superior cleaning of any oxide formations on the surface of the work. More operative skill is required when using direct current straight polarity than when welding with alternating current with high frequency superimposed, principally owing to the absence of the high-frequency pilot discharge when starting the arc.

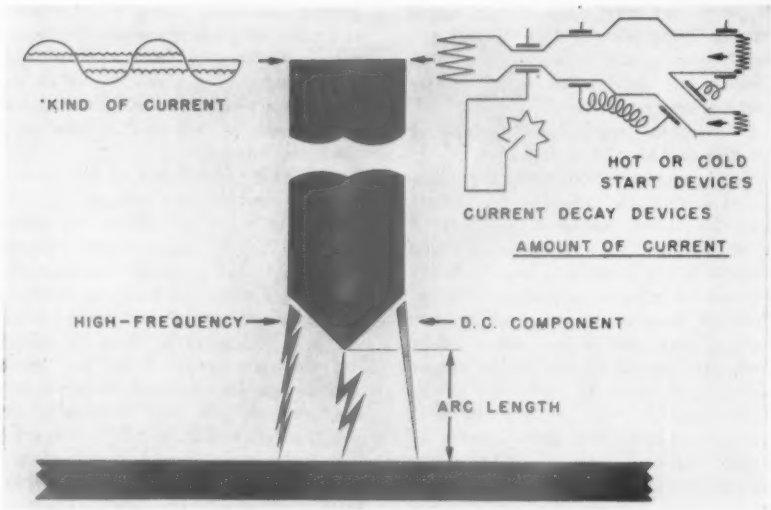


Fig. 2 The important electrical factors are represented

2. How much welding current is required for the work to be done?

Current, which may be spoken of as "heat" supplied for welding, is the most important factor to control in connection with any welding operation, since it determines to a large extent the penetration, rate of progression, rate of metal deposition and quality of the weld. The aforementioned factors are influenced in great measure by a large number of other factors, but the welding current applied to the work at hand is the prime consideration. The welding current should be high enough so that after striking the arc the weld puddle will assume its normal size almost instantly.

3. Is high-frequency stabilization necessary?

The conventional arc-welding transformer does not produce a sufficiently high voltage to positively re-establish the arc in an inert atmosphere after the voltage sine wave has passed through zero. In order to overcome this condition a high-frequency current is superimposed across the arc. High-frequency stabilization produces a stable arc since there is a continuously effective pilot arc produced by the high frequency. It is used extensively in the light metal industries. Most spark gap high-frequency units attached to welding circuits may offer serious interference to radio reception. Steps must be taken to damp out the offending radiation. For those who may encounter trouble from this source, the Joint Industry Committee on High-Frequency Stabilized Arc Welders has prepared an information bulletin, *Recommended Practice for the Installation of High-Frequency Stabilized Arc Welding Equipment.* One manufacturer vends a tube-type oscillator which broadcasts on a fixed wave length with the sanction of the Federal Communications Commission. The assigned wave length is one which does not interfere with radio reception in any broadcast band. Some manufacturers offer circuits which use the high frequency as merely a pilot discharge to start the arc. The high-frequency current is then automatically shut off. This offers a minimum interference to radio

reception and may mean the difference between being permitted to operate the high-frequency unit in the locale without shielding or having to install costly shielding apparatus.

4. What arc length should be used for the gage and kind of material?

To anyone connected with the application of welding, the influence of arc length upon the relative success of the operation is well known. For some metals and alloys it is not possible to avoid porosity without maintenance of a very short arc. However, some variation is possible when welding most metals and alloys. Ideal arc lengths are difficult to prescribe because of the wide range of preference among skilled operators. An arc length of about one-and-one-half times the electrode diameter has been satisfactory for many. In this connection, the greater the arc length, the less is the heat concentration on the weld puddle and the greater is the heat dissipation into the surrounding atmosphere. When welding in an argon atmosphere, comparatively great changes in arc length will not produce significant heat input changes. The reverse is true with helium. Also, altering the volume of argon gas flow will produce no significant change in arc voltage, whereas the arc voltage in a helium atmosphere can be altered as much as three volts by changing the gas flow, the higher flows producing the higher voltage.

5. Must the d-c component in the arc be taken into consideration?

Direct-current component in the inert-gas-shielded arc arises, primarily, from a difference in the material and temperature of the electrodes (the anode and the cathode—one of which will be the workpiece). Other lesser contributing factors are the size of the electrode, the arc length and the kind of inert gas which is used to blanket the arc and weld area.

Rectification occurs in an a-c arc when the arc tends to prevent current from flowing in one direction while offering low resistance to flow in the opposite direction. This condition exists in helium and argon arcs and is dependent upon a number of factors. The rectification causes a direct current to flow when welding with an unbalanced wave a-c welding transformer. The issue of balanced versus unbalanced wave current is highly controversial with strong advocates on both sides.

6. Are the features of the job such that current increase devices might be of benefit?

Certain materials are so prone to thermal shock that it is better to start the arc with current of lower than the specified normal welding value in order to avoid cracking. The current may then be increased manually (by means of a foot-controlled switch) or automatically timed. Starting with a lower current value has the effect of a preheat and the benefits to be derived are those associated with preheating by separate means for other welding processes. Also, when welding with pure tungsten electrodes and heavy welding currents are being used, sections of tungsten may be thrown down on the workpiece when the arc is started unless the tungsten is "warmed" before using the heavy current.

7. Will it be necessary to use current-decay or "crater filler" devices?

For the materials subject to crater checking, it is generally necessary to use special controls to gradually extinguish the welding arc while the inert gas flows for predetermined intervals in order to blanket the weld puddle, rather than by raising the electrode away from the work. Thumb- or foot-operated switches will effectively do this job. Ordinarily, the switch energizes a timed relay which gradually reduces the current at a fixed rate. Use of such devices will reduce finishing costs in addition to avoiding the tendency toward crater checking, arising from shallow or unfilled craters.

Atmospheric Factors

1. What kind of gas should be used for the material?

Argon gives superior oxide cleaning for aluminum, magnesium and beryllium-copper, although both argon and helium have been used for welding most of the common metals and alloys. Mixtures of argon and helium have been used when the greater penetration of helium is desired, but the arc-softening action of argon would be helpful from the standpoint of control. Experimental work has been done with mixtures of argon-hydrogen and helium-hydrogen for the welding of various materials where the occurrence of porosity is a constant problem. "A" nickel is an example of this.

2. Is the gas pure enough for the metal or alloy to be welded?

Only welding grade argon or helium should be used. If commercial argon is used for welding some metals and alloys, the residual gases in the cylinder with the argon will contaminate the material by absorption into the molten puddle, giving a porous structure in the weld. Water vapor in impure helium dissociates in the arc and yields hydrogen and oxygen. The presence of hydrogen in the inert atmosphere causes porosity and the oxygen forms a film over the molten puddle which may impair the ease of the welding operation and result in poor fusion, together with inclusions. The presence of nitrogen in any concentration will impair the speed of the weld progression. For some of the newer metals and alloys which are particularly susceptible to gas absorption in the solid state at elevated temperatures, the welding gas must be of extremely high purity.

3. What gas should be used for the gage of the material?

Helium is ordinarily the better gas to use for mechanized setups because of the greater heat transfer through the arc. Some operators experience difficulty in manipulating the helium-tungsten arc on account of the sharpness of penetration and comparatively great heat liberated by the arc as compared with the argon-tungsten arc. The use of helium as a shielding gas requires considerably more skill than when using argon, as argon makes it possible to have a wide variation in arc length with relatively small difference in heat input. Also, the use of argon will permit more latitude in joint fitup, whereas helium requires great accuracy of joint fitup to achieve maximum benefits, avoid "burnouts" and irregularity of welds.

4. What gas flow should be used for the joint?

Only enough inert gas flow is required to exclude the surrounding air from the weld location. Excessive gas flows may be detrimental to the welding operations and are wasteful. They may cause an unstable arc at low welding current values. Also, undercutting of the work surface adjacent to the weld bead may result.

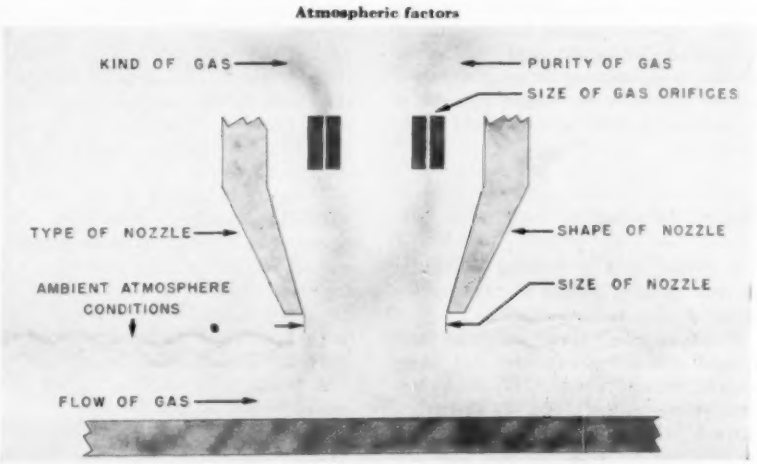


Fig. 3 Factors which have important bearing on the artificial atmosphere conditions

The most important factors which will determine the minimum flow of inert gas to maintain adequate and effective coverage of the welding area are as follows in order of importance:

Shielding gas used
Distance of the gas nozzle from the work surface
Geometry of the weld joint
Size of the gas nozzle
Shape of the gas nozzle
Size of the weld puddle
Amount of welding current
Presence of drafts or air currents
Inclination of the torch
Welding speed
Position of the workpiece

5. What type of gas nozzle should be used?

The three types of gas nozzles are (1) ceramic, (2) metal (cooled by radiation and inert gas) and (3) metal (water cooled). All of these affect the process in various ways. The water-cooled metal nozzles are outstanding from the standpoint of longevity, if properly used. All gas nozzles, whether of ceramic material or of metal, should be kept clean at all times, as an accumulation of foreign material on the inner surface will interfere with or set up turbulence in the gas flow or begin to pass vaporized metal down into the weld puddle. It is necessary to use the ceramic type of gas nozzle whenever possible, if high-frequency current is being used. This will prevent cross-firing to the gas nozzle which must be anticipated periodically if metal nozzles are used. However, when amperages of 250 and above are reached, water-cooled nozzles must be used. Arcing to the metal gas nozzle can be offset, to a degree, by using the largest size nozzle that is practical for the specific application. The sleeve-type (or slip-on) type of metal gas nozzles are very limited as to current-carrying capacity and are more prone to damage and misuse than the water-cooled types, owing to their delicate nature. The ceramic nozzles become brittle after continued use and must be replaced when the lip of the nozzle becomes rough and uneven, which will disturb the gas flow.

6. What size of gas nozzle should be used?

When choosing a gas nozzle for the specific job, an attempt should be made to use the smallest nozzle whose lip will not fuse down under the concentrated heat of the arc (assuming a ceramic nozzle is being used). A small nozzle will assist in maintaining a more stable and positive arc, permit welding in restricted areas and give better vision. There is some "compression" effect around the arc offered by the gas stream from the smaller nozzle, which tends to make the arc more forceful, direct and concentrated. However, the larger nozzle will give a better atmosphere blanket at a slower gas discharge rate than would be the case with the smaller nozzle. For metals that are sensitive at elevated temperatures to contamination from the ambient atmosphere, the larger nozzle gives a better safety margin.

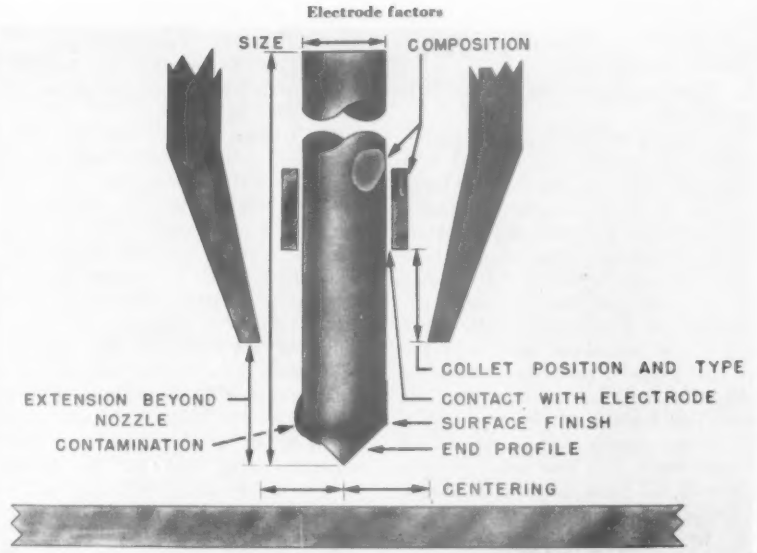


Fig. 4 Representation of the important factors connected with the electrode

7. What shape of gas nozzle should be used?

The common form of gas nozzle is either cylindrical or tapered in the inner surface. Other types are available which turn in toward the electrode and severely restrict the orifice size, but give excellent vision of the weld puddle. For special purposes, nozzles may have a section flared out or formed in such a manner that the gas flow may be altered and thus achieve a special effect, such as maintaining protection over the finished weld area for a longer period than would be the case if a standard nozzle were used. For welding the materials which may be contaminated with gas at elevated temperatures, elongated gas nozzles have been found very helpful. These should be of a form that will trail well behind the arc location itself. When it is necessary to weld in very restricted locations, special torches can be fabricated for that purpose.

8. What atmospheric conditions exist?

Certain conditions of humidity and temperature of the ambient atmosphere give greater entrainment of air into the column of inert gas issuing from the gas nozzle. This is a matter for further investigation. The gas column must be shielded against stray drafts or air currents to prevent contamination. If local a conditions are very disturbed it may be necessary to increase the gas flow through the torch to maintain adequate coverage of the immediate weld area. Some experimental work has been done with a view to developing gas nozzles which will be less sensitive to air contamination of the issuing gas column.

9. Are the gas orifices in the collet large enough to avoid turbulence in the issuing gas column?

Less turbulence and mixing with the surrounding air occurs if the gas column issues from the nose of the gas nozzle with a minimum of deflection. In order to obtain this condition it has been found necessary to provide larger collet orifices in certain cases. In most collets it is not too difficult to provide for more efficient gas flow by merely enlarging the size of the passages. Usually this can be done without seriously impairing the structural strength of the collet.

Electrode Factors

1. What type of electrode should be used?

Four electrodes may be used with this process: pure tungsten, thorium-tungsten alloy, zirconium-tungsten alloy and carbon. Pure tungsten is the electrode in most common use although it is being replaced by the other two alloy electrodes because of their longer service life. They are more expensive than the pure but the additional cost is justified by the much longer predictable life. Carbon electrodes are desirable because of the easy-to-start, easy-to-control arc, but deteriorate rapidly in use, are brittle and require constant resharpening. There is some passage of carbon into the weld melt and this is detrimental to certain materials. This must be investigated from the metallurgical standpoint before its use is indicated for the individual job.

2. What size of electrode should be used?

Generally speaking, the electrode size should be chosen so the electrode will operate near its maximum current carrying capacity. By so doing, the heat of the arc is more concentrated, assuring maxi-

mum penetration, a stable arc, high welding speeds and a minimum size (width and convexity) of weld bead.

3. What profile will be best for the electrode end?

The electrode end profile may be square, hemispherical, greater than hemispherical or pointed. However, the thoriated tungsten and zirconium tungsten electrodes are the only ones which will maintain their prepared end profile over an extensive heat range, as the other types will either change their end profile, or gradually slough off, as in the case of carbon electrodes. The pointed end sometimes used with the thoriated tungsten electrodes is ideal for welding in restricted locations, such as narrow joint kerfs on stainless steel piping. The current density may be maintained at an extremely high level that cannot be used with the pure tungsten or carbon electrodes.

4. What surface finish will be suitable for tungsten electrodes?

Tungsten electrodes can be obtained in several different finishes which result from the various operations by which they may be manufactured. For most stable arc characteristics, the centerless-ground electrodes are best. The relative smoothness of the electrode surface has considerable effect on current-carrying capacity due to the increased surface resistance of the rougher electrodes.

5. How far should the electrode end be extended beyond the nose of the gas nozzle?

Projection of the electrode beyond the nose of the gas nozzle is ordinarily determined by the profile of the joint or seam to be welded, although other factors have some influence. An inside fillet weld requires the greatest electrode extension in order that the electrode may approach the heart of the joint and yet permit some vision of the weld puddle, which would not be the case were the end of the electrode at its normal position with regard to the gas nozzle nose. Opposed to this extreme is the upstanding flange weld, in which case a very slight extension is required. It is seldom necessary to extend the electrode further than $1/2$ in. which is considered quite excessive. Most operators prefer an extension of about $1/4$ in., although gas coverage can be obtained more economically if the extension of the electrode is about one and one-half times that of the diameter of the electrode itself.

6. Is the electrode centered within the orifice of the gas nozzle?

If the electrode is not centered in the gas nozzle two things may occur: (1) There may be insufficient gas coverage of the weld puddle due to the electrode end not being centered in the issuing gas column. (2) If heavy currents and ceramic gas nozzles are being used, the electrode may be close enough to the lip of the nozzle to cause it to fuse. Contaminating gas will then come down with the inert gas and force the operator to stop welding.

7. Have the operators been instructed about contamination of electrodes with base or filler metal?

The greatest usage of electrode will be found due to accidentally "striking" the workpiece with the electrode, or accidentally touching the electrode with the filler rod, should one be used for the operation. Another cause of electrode consumption comes from failure to properly shield the electrode after extinguishing the arc. The contamination of tungsten electrodes is annoying, not only from the standpoint of defacing the workpiece, but the loss of welding time while the tungsten electrode is being cleared of the base metal plated on its surface or alloyed with it. Under normal welding conditions the thorium- or zirconium-bearing electrodes will not contaminate the workpiece, but the pure tungsten will alloy with it.

8. What type of collet will be best for the work at hand?

Collets may be of either the screw or the draw type. The main consideration is the effectiveness with which the collet will conduct current to the electrode. Another important item is the relative ease with which the electrode may be adjusted. The draw type is far superior in this particular respect. Also, the screw type is more prone to be damaged, due to improper handling.

9. What is the collet position with relation to the nose of the gas nozzle?

From the standpoint of rapid withdrawal of heat from the electrode, it would be ideal if the collet could be brought immediately adjacent to the molten tip of the electrode. However, if this were done, the disturbance of the gas flow would be so serious that a great deal of turbulence would occur, with the probability that the weld puddle would be improperly shielded by the inert atmosphere and the arc might become wild and unstable. Conversely, if the collet is fairly far back in the gas nozzle the gas column will be relatively undisturbed but the electrode will run hotter. The position of most electrode collets is a compromise between the two extremes.

10. Is the collet material suitable for the amperage to be used?

The efficiency of heat withdrawal from the electrode and the surface resistance to the passage of current may be controlled to an extent by changing the material of which the collet is made. If collets are made of copper, the heat transference through the bronze torch head into the water chamber will be improved and the tungsten will operate at a lower temperature which will make posssible the use of higher current density.

11. Is the collet in proper contact with the electrode?

The inner surface of the collet should be completely smooth. Before any collets are placed in service they should be checked for burrs which might affect the efficiency of contact with the electrode. It is as essential for the inner surface of collets to be smooth as it is for electrodes to be free of irregularities.

Workpiece Factors

1. What about the skill required to do the job?

The skill of the operator is a feature of the application of any welding process. An operator must be available who can efficiently do the job. In the matter of training, the fabricator must determine whether it is going to be to his best interest to train his operators for a single operation weld or whether he will take the broader viewpoint in preparing them to meet the requirements of any work they encounter. As previously noted, the work at hand should be analyzed with a view toward approaching it by scientific procedure. The skill of the available operators will have strong bearing on this point. The nature of the work may be such that manual methods will be more economical than mechanized welding. If

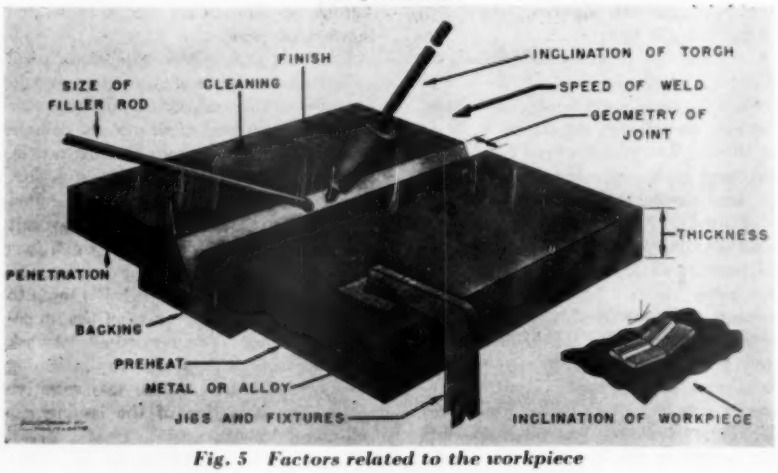


Fig. 5 Factors related to the workpiece

machine welding is to be used, process data applicable to the work at hand must be available. To achieve statistical control of welding, methods requiring a high degree of skill on the part of the operator must be eliminated to the greatest extent possible. The high fixed cost of the inert-gas-shielded arc welding apparatus must also be considered when determining whether an operation is economically practical.

2. Have the metallurgical characteristics of the material been considered with relation to the welding operation to be performed and the weldment to be fabricated?

Metals and alloys to be welded should be considered from the standpoint of practicability of fabrication without involving excessive cost. The material composition, physical structure and form have strong bearing on this.

The principal considerations involved in order to obtain a sound, metallurgical structure in the weld which will have the properties required for the specific weldment are:

(*a*) Composition of the weld metal.
(*b*) Composition of the base metal.
(*c*) Effect of change of composition in the weld metal due to dilution with the base metal.
(*d*) Effect of temperature and rate of temperature change in the weld metal and in the base metal.
(*e*) Effect of welding technique and sequence on the weld metal and the base metal.
(*f*) Mass and distribution of mass with relation to the weld joint.
(*g*) Service conditions to which the weldment will be subjected.

It is not possible to detail the foregoing within the scope of this paper. Comprehensive literature pertaining to the specific items is obtainable from many sources.

3. What geometry will be proper for the joint?

The joints may be divided into two major groups; those requiring no filler metal, in which the joint provides the metal for the weld, and those in which the weld metal is separately added to the joint. the "ideal" inert-gas-shielded arc weld joint is one in which the arc is merely "tracked" by manual or mechanical means over the length of the seam and without the addition of filler metal. The operator's technique is thus reduced to the simplest manipulation possible. However, if the joint is to provide the weld metal itself, the weld joint preparation must be extremely accurate, which is often not justified by the job conditions or the complexity of the weldment itself. A joint which requires the addition of filler metal by separate means requires the development of some skill on the part of the operator which is somewhat more critical than with the other welding processes. Also, it should be determined that the torch adjustment factors are suited to the joint geometry. Equipment must be available to properly prepare the joint. Before welding it should be determined that the fit-up is sufficiently accurate to successfully weld the joint. The position and accessibility of the joint location may have considerable bearing on the geometry of the joint. The joint groove must be such as to provide for complete penetration of the closure pass through the weld root. If the joint root landing is too thick, irregular penetration may result. Also, it may be difficult to obtain uniform penetration if the groove opening is too narrow, especially if the joint is in the vertical, horizontal or overhead position.

4. Have the mechanics of the welding operation been considered with relation to the thickness of the material?

It must be determined that the equipment available is adequate for the thickness of the material, whether it be particularly thin or whether very heavy sections are to be joined. If the sections are very heavy it will probably be more practical to join with the inert-gas-shielded consumable electrode process. If the sections are very thin, it may be necessary to use rather elaborate jigs or fixtures and resort to mechanized welding. The joint must be planned so that adequate penetration can be obtained with a minimum requirement for filler metal.

5. Has the position of the weld joint been considered with regard to the skill of the operators who will do the production work?

Standard joints may be welded with this process in any position. However, greater speed and economy will be attained by welding in the flat position for most fabrication. Any departure of the work from the horizontal plane will profoundly affect the adjustment of the process factors. The prime consideration involved in this particular instance is the influence of gravity upon the molten weld puddle and the relative degree to which it may be displaced. As one example: the joining of heavy plates may be expedited by inclining the joint slightly upward in order to permit carrying a wider and deeper body of molten metal, which would otherwise tend to run ahead of the arc and form cold laps with the base metal. Another example is the corner joint which may be welded with greater speed by traversing the seam vertically downward. Butt joints in very thin materials may be handled in similar manner, as inclining downward may give speeds of the order of several hundred inches per minute.

6. What inclination of the torch to the joint should be used?

The geometry of the joint, the fluidity of the metal or alloy being joined and the position of the joint all influence the inclination of the torch to the workpiece. The three considerations are (1) visibility, (2) heat application and (3) required direction of gas flow. Ease and convenience for the operator are the conditions to be attained.

7. What diameter of filler rod should be used for the joint?

Choice in the size of filler rod should be determined by deciding which rod offers the minimum interference to the welding operation. Ordinarily, the more skilled the operator, the larger the filler rod he will prefer to use. The smaller the rod, the faster it will have to be fed into the weld puddle to maintain a proper weld bead. If the filler rod is too large it may affect the efficiency of the inert gas pattern on the workpiece. Also, it may interfere with the evenness of the deposit or cause cold laps to form intermittently. Generally speaking, the largest filler rod which can be conveniently inserted into the molten puddle without "freezing out" or striking the gas nozzle is the one to use.

8. What type of jig or fixture should be used for the work at hand? One overriding consideration governs the use of jigs or fixtures; namely, the jig or fixture must pay for itself either by increasing production or improving the product quality in such a way that the cost will be amortized within a reasonable length of time. It is impossible to attain high-quality mass production weldments without use of jigs or fixtures. Mechanical or hydraulic jigging, with the attendant possiblity of using automatic or semiautomatic equipment, is indicated where there is a large number of similar weldments to be fabricated. Some common welding difficulties are particularly annoying when they are encountered while welding on work in a jig or fixture. These are as follows:

(*a*) A variation in welding machine power factor.
(*b*) Arc length may be improperly adjusted and inconsistent.
(*c*) Irregularity in abutting sheared sheet edges.
(*d*) Centerline of weld joint may be improperly aligned.
(*e*) Impure blanketing atmosphere, caused by loose connections, air drafts, etc.
(*f*) Inadequate cleaning of sheets preparatory to welding.

Corrective measures to be used with regard to the foregoing must be considered individually. Weld backing, if done by metal, must be considered as a feature of the welding jig or fixture. Backing of the weld may be by metal, gas or flux. Metal backing helps to control distortion, may be made an integral part of the jig and prevents excess weld penetration, but is the most costly form of backing. Gas backing with argon, helium, nitrogen or fired-hydrogen offers excellent protection for the backside of the weld metal but does not prevent excess weld penetration or give any control of distortion and is comparatively costly. Flux backing which may be used on some materials is easy to

apply, but may be very difficult to remove after use and gives no control over distortion. Silicone putty weld backing is easy to apply and remove and gives a measure of control of excess penetration; however, no control of distortion is obtained through its use. Economy in the use of backing gases cannot be overemphasized as the cost of purging with inert gas may represent a substantial proportion of the total gas cost for the entire operation.

9. Is the finish of the weld to be such that special welding procedures must be used to attain it?

For most applications the exceptionally smooth surface of the welding done with this process reduces finishing costs to a minimum. For certain stainless steel weldments a superior appearance has been obtained by smoothing the finished surface of the weld with a weaving motion of the torch, but without the addition of filler metal. However, the use of this procedure may be detrimental for surfaces exposed to highly corrosive service. Where arc burns or scars on the surface of the workpiece would be detrimental it is helpful to use sections of copper adjacent to the weld seam. The arc may be struck on the copper block and brought over onto the weld joint without interruption. Arc gouging on stainless steel, aluminums and the high-temperature alloys, in particular, is very annoying as such imperfections often require much more grinding and polishing than would otherwise be necessary.

10. What preweld cleaning is necessary?

Mountains of literature relative to the various techniques and processes that are used for cleaning metals and alloys to be welded are available from the various vendors. It is most important that a simple easy practical approach to cleaning problems be used. The primary consideration is removal of any material which would interfere with the application of the welding process. This may involve a time factor between cleaning and welding, as some materials must be welded within a certain time interval after cleaning has been done.

The various methods used for cleaning prior to welding operations are as follows: Soak alkali cleaning, soak emulsion cleaning, soak acid cleaning, machine cleaning, electro-cleaning, barrel cleaning, steam cleaning, petroleum spirit cleaning, vapor degreasing, acid pickling, electrolytic pickling, salt bath cleaning and descaling, blast cleaning, brushing and flame cleaning. Although it is possible with the proper technique to join the various metals and alloys with only meager cleaning of the abutting edges, any foreign material such as oxide, dirt, oil, grease, etc., will adversely affect the speed of weld progression and may seriously impair the physical characteristics and appearance of the finished weld section.

11. Is the welding speed, sequence and technique proper for the work at hand?

The procedure should be so arranged and planned that the speed of weld progression is faster than that of the heat transfer in the base metal. If this condition can be attained, a unit heat will always exist at the weld puddle, operator fatigue will be materially reduced and production will be maintained at a high level. Exceptionally high welding speeds are apt to impair quality to the extent that finishing costs may become troublesome, which will tend to offset the benefit of the greater speed obtained. If the operation is manual, operator skill has strong bearing on the production level which can be attained. It may be necessary to train operators to do the specific job and it must be determined whether or not this is economically feasible in terms of possible profit to be realized from the work at hand and the cost of training the operators. The welding sequence must be laid out in such a manner that the finished dimensions and distortion resulting from the welding operation will be within tolerable limits. The welding technique must be specified in detail if the joint is to be manually welded.

CONCLUSION

Inert-gas-shielded arc welding is a process that cannot be successfully applied without thorough consideration of the factors affecting statistical control. A breakdown of the various factors reveals that none is complicated and that adequate reference information is available. If the various factors are considered individually and collectively with reference to the specific application, the process can be efficiently applied.

ACKNOWLEDGMENTS

The author wishes to acknowledge the helpful suggestions offered by J. M. Fox, Jr., Plant Metallurgical Engineer, Manufacturing Department, General Electric Co., Hanford Atomic Products Operation; Myron A. Pugacz, Welding Engineer, General Electric Co., Aircraft Nuclear Propulsion; Walter L. Fleischmann, Metallurgy Section, General Electric Co., Knolls Atomic Power Laboratory; and Thomas G. Kiakona, Pipe Department, Kaiser Engineers, Hanford Works. Appreciation is extended to those who have authored welding trade literature since the advent of this welding process, as most present industrial knowledge of its application has been developed through their efforts.

AN OPPORTUNITY —is presented to all AWS Membership and Industry to secure back numbers of The Welding Journal Bound Volumes at very low cost.

Effective now, a limited supply of the following BOUND VOLUMES are available at the prices shown.

Year	Price	Year	Price
1930	$6.00	1938	$ 6.00
1931	6.00	1948	10.00
1932	6.00	1950	12.00
1933	6.00	1951	12.00
1934	6.00	1952	12.00
		1953	15.00

Foreign postage additional

Each consists of the twelve (12) issues of that year's JOURNALS, each volume attractively bound in imitation black leather covers. These are valuable additions to your engineering and welding library.

Place order *now* with the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, N. Y. Add 3% sales tax on N.Y.C. orders.

Current Rectification and High Frequency Interference in Inert Gas Welding

A method has been developed for preventing undesirable current rectification and high frequency interference in inert gas welding

by J. G. Murray

THE old saying, "there is nothing new under the sun" holds true in welding development as in other matters. Since the time when the title was chosen for this paper, articles have come to the author's attention indicating that the British have advanced a method of overcoming high frequency interference that parallels some of the observations made here. Recognizing this fact and acknowledging the fact that most new ideas are based on a reworking of accepted principles, this paper is presented as a "method"—whether it is new or not will depend upon the reader.

Before going into an analysis of this method, it would appear to be worth while to explain the problem and the various terms involved. While it is undoubtedly common knowledge to many, a little background on the inert arc might be helpful to the uninitiated.

In very early attempts at manual arc welding, it was found that the molten pool was subject to the ravaging effects of the atmosphere, causing pinholing, oxidation, etc. At the same time that research was being done to uncover some sort of chemical mixture that could be added to the arc to diminish this effect, other research was aimed at welding in atmosphere other than air. Various patents were issued for apparatus and methods of introducing this atmosphere to the arc. Hydrogen was the gas most commonly tried with very discouraging results. Helium and argon, true inert gases, were virtually unknown at the time. With the successful introduction of chemical flux coatings on steel welding rod, attempts to introduce an inert gas to the arc became fewer and fewer. During this early state of development there were some metals that resisted this coated rod approach such as stainless steel, aluminum and magnesium. Although improved rods made possible the welding of stainless, aluminum welding could be accomplished only with difficulty and magnesium not at all. Probably the first commercial production welding of a difficult metal to gain public attention was done by Northrup Aircraft, Inc. in 1940, when they successfully joined magnesium in aircraft fabrication. This was not done by a metallic, coated electrode but by introducing a shielding atmosphere of inert gas, helium, to a nonconsumable electrode at the arc. With the booming of the aircraft industry during the war, work along this line mushroomed at a rapid rate. Argon was finally extracted from the air in sufficient purity to be used for inert gas welding. Both helium and argon are being used now for a shielding atmosphere.

Of course, some work had to be done on the electrode that would maintain the electric arc. For the manual welding process, a nonconsumable electrode was found to be best. Carbon was preferred in some cases while tungsten gave better results in others. In the a-c welding of aluminum, tungsten was and still is being used, but the application of thoriated tungsten appears to be gaining favor.

When it came to choice of power supply, ac and dc were tried. For the early work on magnesium d-c reversed polarity (electrode positive) worked best. In general, it may be said that for the nonconsumable electrode in inert gas, more heat (and penetration) is obtained at the work with straight polarity (electrode negative) than with reversed polarity. Electrode positive causes concentration of heat in the electrode. Since electron flow is always from negative to positive, this flow has a noticeable cleaning action on some metals such as magnesium and aluminum.

The original attempts to weld aluminum with the inert arc and dc were only partially successful. Electrode negative required a special flux that was difficult to prepare and use. Electrode positive, with its excessive heat at the electrode, reduced their current-carrying capacity. Sixty-cycle alternating current, with its reversal from positive to negative, gives a compromise between the d-c effects.

In the early stages of this process there were un-

J. G. Murray is Project Engineer of the Lincoln Electric Co.

Presented at the Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19–23, 1953.

doubtedly instances where aluminum was successfully joined together with a-c transformer type welders of the standard design. The metal thicknesses and current ranges were very narrow because of difficulties encountered with the arc at low current. Early arc torches were incapable of handling high currents as we know them today, resulting in a rather limited band of usefulness.

One problem that could not be tolerated in these early welds was the fact that touching the electrode to the work contaminated the weld at that point and often spoiled the working tip on the electrode. Starting tabs were of little value when the arc went out in the middle of the seam. Obviously some spark was needed to bridge the gap from electrode to work when the two were brought in close proximity.

Anyone exposed to high-school physics since the advance of radio has seen demonstrations using high-frequency, high-voltage sparks to bridge a gap in air. Usually the demonstrator mystifies his audience by making a neon bulb light just by holding it in his hand and without having any wires connected to it. Because the supply is high frequency it does not constitute a hazard to personnel. It does ionize and break down the air gap which was the very thing needed for inert arc welding.

Using a special high voltage transformer, spark gap and condensers, attachments were soon commercially available that were highly advertised as the answer to the aluminum welding problem. Some of these units incorporated shut-off valves to control the flow of gas and the flow of water for the water-cooled torch. In many instances machines being offered on the market today are nothing more than the standard welding transformer, spark supply and control valves consolidated into a single unit.

Through the use of these machines, numerous problems have been encountered. Some of these showed up in the field while others manifested themselves when attempts were made to increase the versatility of the inert arc under laboratory conditions. Practically all of them hinged on two subjects, rectification and radio interference.

To explain what rectification is we must first consider that the welding current wave shape of the a-c transformer type welder, when used on conventional arc welding, is primarily sinusoidal, fluctuating above and below the zero axis at line frequency (usually 60 times a second).

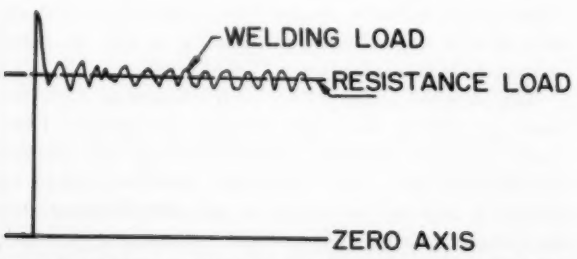


Fig. 1 A direct current trace. The greater the value of the welding current, the greater the distance between the trace and the zero axis. The dotted line indicates pure resistance load

In Fig. 1 may be seen a copy of the picture a direct-current welding condition would present on a cathode-ray oscilloscope. The greater the value of welding current, the greater the distance between the trace and the zero axis. (For clarity a dotted line indicates pure resistance load which is simply the average of the jagged current trace.)

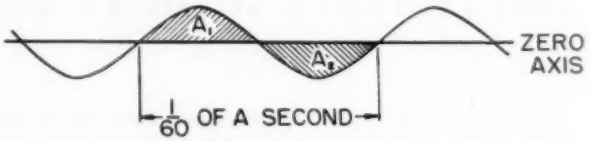


Fig. 2 Alternating current trace represents what is happening 60 times a second when the power supply is 60 cycle

Figure 2 represents a similar condition but now the welding supply is a transformer. This picture represents what is happening 60 times a second when the power supply is 60 cycle. In general, the area of the loops above the zero axis match the area of the loops below the zero axis (A_1 equals A_2).

Going to a tungsten electrode and an aluminum plate, this symmetry no longer exists because of the dissimilarity in the metals. The electrode, since it is connected to an alternating current source, is changing from negative polarity to positive polarity in every cycle. Apparently when the tungsten is negative the electron emission is better than when the tungsten is positive. This causes a larger current loop on the side of the zero axis when we have electrode negative than we have on electrode positive (see Fig. 3). For one complete cycle we have effectively a direct-current component of straight polarity. The introduction of this d-c component is called rectification.

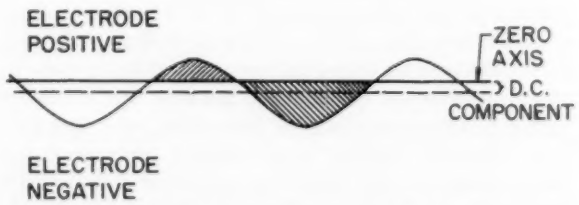


Fig. 3 Represents d-c component called rectification, the condition resulting when using a tungsten electrode with an a-c power supply

If present in small percentages, this component may cause no apparent welding trouble which is the case on heavier plate. On thin gage material this component can overcome the effective advantage of the alternating current, act like a direct current arc and fail to join the metals.

The end result of a d-c component can be a burned-out transformer. This direct current is not usually apparent until it is too late. The direct-current flow, while welding, circulates through the secondary of the transformer. This means the iron section is quite likely

to become saturated (in terms of flux density) which calls for a primary current above that normally encountered. With this increase in current comes extra heating. The insulation breaks down from the heat, shorting out the primary of the transformer. The end result may be noise, fire, smoke and dissatisfaction on the part of both operator and management. This holds true when operating near the top third of the output range. At lower current settings, the transformer may stay within safe temperatures.

The only solution to the problem was to eliminate rectification or to at least get it down to a percentage small enough to not be objectionable. To do this, condensers or batteries can be used. Condensers naturally act as a block to any d-c component. From a commercial standpoint, they have one drawback, especially when used on machines with high output current (large welding capacity). The condensers must carry the welding current so the larger the machine the more condensers needed. Hardly being what one would consider inexpensive on small machines, the investment in condensers on the larger machines is a sizable part of the cost.

Lead acid storage batteries which are rugged and relatively inexpensive, do a satisfactory job of cancelling out this direct current. Their usage does not represent a new idea as they were found to be effective several years ago. Since they can be kept at full charge with a built-in trickle charger, and since they do stand up in use, there is every reason to believe that they are commercially acceptable for the application.

Pinpointing now the other problem of radio interference, we find that not only was the original high-frequency, high-voltage spark necessary to start the arc, but it was also necessary on many applications to keep the arc from going out. Originally there were no objections, and, therefore, no reason why this high frequency could not be maintained.

Basically the power of these spark suppliers gives a signal similar to those sent out by radio and television broadcasting transmitters, but with a shorter range. The range is sufficient to cause interference on police radios, neighborhood radios and television. Under certain weather conditions, this frequency can "skip" and cause interference many miles away.

At present there is a statute available to the Federal Communications Commission prohibiting the use of industrial equipment causing interference of this nature. Although it is not being enforced as yet, there is little doubt that it will be, once interference-free equipment becomes generally available.

Returning to the dissimilarity between the tungsten electrode and the aluminum plate previously mentioned, laboratory work has indicated that the ionization breakdown is more difficult when the tungsten is positive than when the tungsten is negative. Obviously, something new had to be introduced to sustain the arc when the electrode was positive. Previously the high-frequency spark occurred often enough and was strong enough to carry the arc over the weak spots.

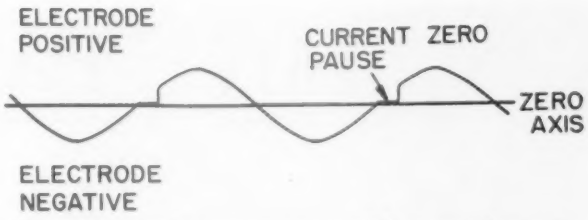


Fig. 4 Represents a current trace with a span of nonconduction where the line is along the zero axis

Figure 4 represents a current trace with a span of nonconduction where the line is along the zero axis. Figure 5 is a voltage trace of the same condition. The arc starts to go out and voltage rises toward open circuit when an external spark reignites the gap causing resumption of current. The conventional method of introducing high frequency would show an intermittent trace of high voltage magnitude with many impulses liberally applied throughout the welding voltage cycle.

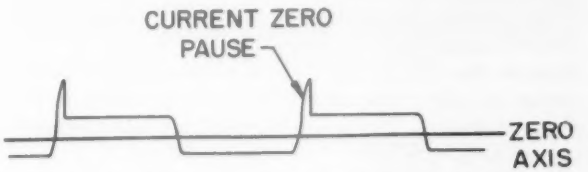


Fig. 5 A voltage trace of the same condition

Further use of the cathode-ray oscilloscope to observe the current wave shape indicated that the closer an attachment could come to injecting the needed boost at a particular point in the tungsten-positive part of the cycle, the less power required. This means that if the spark could be guaranteed at the point of current zero pause on every cycle, the surplus sparks could be omitted. Such an arrangement would minimize the power surge requirement and keep the signal well below the radio interference level.

There are a number of methods of accomplishing the consistent insertion of a spark boost at the proper point in the cycle. Without going into detail, it is apparent that a synchronous motor or a vibrating relay could be used to mechanically make contact at the same point in every cycle. Proper phasing of a transformer supplying a spark gap or an electron-tube triggering circuit are two other methods of obtaining the correct correlation. From here it is only a matter of testing the various methods to determine the one that will give the maximum in service for the minimum in customer cost.

The final conclusions are, first, that a lead acid storage battery offers a practical solution to the problem of overcoming the direct current component in rectified alternating current. The second conclusion is that a comparatively weak spark, introduced at the exact same instant in every alternating current cycle, will give good consistent inert arc welding over the entire range of the transformer without the problem of radio interference.

EDITORIAL PREVIEWS

New Kearny Generating Station—Public Service Electric and Gas Co.

THE new Kearny Generating Station is located adjacent to the original station, which was placed in operation in 1925 and 1926. The rapid progress in the art of generation of electricity by the use of steam is apparent by comparing the new units with those in the old station. The turbine-generators have tripled in size. The steam pressure is almost seven times as great. The steam temperature has increased almost 50%.

In the two new Kearny boilers 410,000 gal of oil or 2300 tons of coal are burned every day. This daily amount of fuel is enough to last the average home owner over 200 years.

The boilers, each as tall as an 11-story building, produce a million pounds of steam an hour at a pressure of 2350 lb/sq in. and a temperature of 1100° F, the highest steam temperature for power generation in the United States.

The steam is carried to each turbine through two 9-in. OD stainless steel pipes, with walls $1^1/_2$ in. thick. These 80-ft long pipes, made up of 20-ft sections welded together, costing $800 per foot, are forged and bored just like gun barrels. The pipes, beneath their protective insulation, glow a dull red as the high-temperature steam flows through them at a speed of approximately 15,000 fpm or 170 mph.

GENERAL ARRANGEMENT

This new station has, for its principal equipment, two turbine-generators and two boilers arranged in the unit system. The entire plant is operated from a control room located at operating floor level in the center of the square formed by the four major items of equipment. The new units are operated as a separate station with practically no ties, electrically or mechanically, with the old station. The boilers are close to the turbines, hence the steam leads are short. The coal pulverizers are placed alongside and between the boilers and are enclosed in a separate ventilated room. The feeders of all pulverizers are accessible from one platform.

The new Kearny Generating Station is designed for two-level operation, with the two levels only 15 ft apart, effecting a saving in first cost estimated at $300,000 for the two units.

All parts of the boilers are out-of-doors except the burner areas and the bottoms of the furnaces. The top drum and the three steam headers of each boiler are enclosed in the boiler casing. Building volume is significantly reduced from that required for a complete enclosure.

Fig. 1 Sidewall panel construction, No. 7 Unit Boiler

Fig. 2 Welding of 12-in. downtake to upper steam drum

Fig. 3 General view, front wall panels

STEAM GENERATING UNITS

The unusual features of the new Kearny boilers include controlled circulation, pressurized firing, twin furnaces, flue-gas recirculation and higher steam temperatures and pressures. These boilers have divided furnaces of continuous discharge, wet-bottom type. They are equipped to burn either coal or oil. Each of the twin furnaces is about 20 ft square. The dividing waterwall has large openings to equalize furnace pressure.

Gas-leak tightness of the pressurized furnace is attained by making the pressure barrier at the waterwall tubes, each of which is welded to a bar spacer placed between adjacent tubes. Most of the joining for this construction was done in the shop, and the waterwalls were shipped to the site in panels ranging in width from 15 to 24 tubes, and in length from 24 to 49 ft.

These panels were welded together in the field to form a continuous gastight envelope for the furnace, using the inert-gas first pass technique, with filler rod added, and completing the welds by the manual arc process, this being the first application of this method in field boiler erection. Since the waterwalls are tight, the necessity of constructing the furnace casing to be leaktight was avoided. It also effected a saving in the erection cost of the waterwalls due to fewer field welds.

TURBINE-GENERATORS

The turbine-generators are unique in respect to their elevated steam conditions: 2350 psig, 1100° F at throttle and 1050° F reheat temperature.

The side exhausts in the lower half of the low-pressure element along with the use of split condensers make it possible to place the operating floor only 15 ft above the ground floor. The turbine exhausts are welded directly to the condenser inlets without expansion joints.

WELDING

Welding has played an extremely important role in the design and construction of this station. Without the development to a high degree of perfection of techniques for welding ferritic and austenitic steels of various types, it would have been impossible to build and operate a plant employing steam at 2350 psig and 1100° F, in which it is essential to eliminate as far as possible all flanged joints. Electric arc welding was mostly employed. The development of the inert-gas first pass technique was advanced and used in the welding of boiler tubes and austenitic main steam and turbine inlet pipes without backing rings for the first time.

New Automatic Welder Used in Laying Longest Aluminum Pipe Line

A NEW portable automatic welding machine, used during the laying of the longest aluminum pipe line ever installed, has performed so rapidly that it passed the ditching machines and worked on ahead of them—a feat rarely accomplished in hand-welding operations.

The new machine is being used in laying of the 12-mile high-pressure pipe line between the White Point gas field near Corpus Christi, Tex., and the Reynolds Metals Co.'s LaQuinta alumina plant. It is claimed that the new automatic welder, developed by Air Reduction Sales Co. in conjunction with Reynolds, makes aluminum pipe line competitive with steel in cost, without considering many additional advantages of aluminum pipe.

The machine welded 40-ft sections of $8^5/_8$-in. aluminum pipe in an average time of 4 min for a 5-pass weld, compared to about 8 min or more for welding pipe in place by hand, the method commonly used for steel pipe and which heretofore has created technical problems in the welding of aluminum pipe. Suspended over the line by a side boom, the automatic welder is equipped with quick-acting clamps which securely grip the pipe. Pressing a button starts the welding, and automatic controls maintain proper conditions at the arc. When the weld is complete, the machine automatically stops, reverses itself, and returns to the starting position. The clamps are then released, and the machine moves to the next weld.

W. B. Moore, Reynolds' manager of chemical and petroleum market sales, said: "Development of an automatic method of welding has been the missing link in making aluminum competitive with steel pipe for high-pressure gas lines." Mr. Moore explained that aluminum already is competitive for low-pressure gas and oil lines, such as field gathering systems.

"I believe you will see several substantial aluminum gas line projects started in the next year or so as a result of this new welding technique," Mr. Moore stated. The largest diameter pipe now made by Reynolds is 12 in., but the aluminum firm now is planning facilities at its Phoenix extrusion plant for manufacture of pipe up to 32 in. in diameter.

The welds made during the laying of the 12-mile high-pressure link were subjected to pressure as high as 1800 psi, and held firmly. The 40-ft aluminum pipe sections used weigh only 320 lb while the same size section of steel pipe weighs about 1000 lb. Reynolds technicians pointed out that this makes possible savings in handling, equipment and labor which virtually offset the higher cost of aluminum pipe.

Fig. 1. Pipe was strung quickly and lined up for welding using standard auto bumper jacks for leveling. Two men easily placed pipe on jacks and leveled. Joints were then clamped in alignment and tack welded at three points around circumference using standard Aircomatic welding gun

The group of petroleum and welding experts who witnessed the Texas demonstration were told that aluminum pipe has many additional advantages over steel; aluminum is noncorrosive, and is not attacked by the sulfur present in "sour" crude oil.

Although pipe in the new White Point-LaQuinta line is wrapped, this is unnecessary in many instances. If aluminum pipe is wrapped, it does not require cleaning after storage to remove mill scale or rust. Wrapping of aluminum pipe therefore costs about 30% less than for steel.

Maintenance costs for aluminum pipe are notably lower, Reynolds spokesmen said, because painting of aluminum used in overhead or exposed installations is unnecessary, while steel must be carefully painted and maintained to prevent rust.

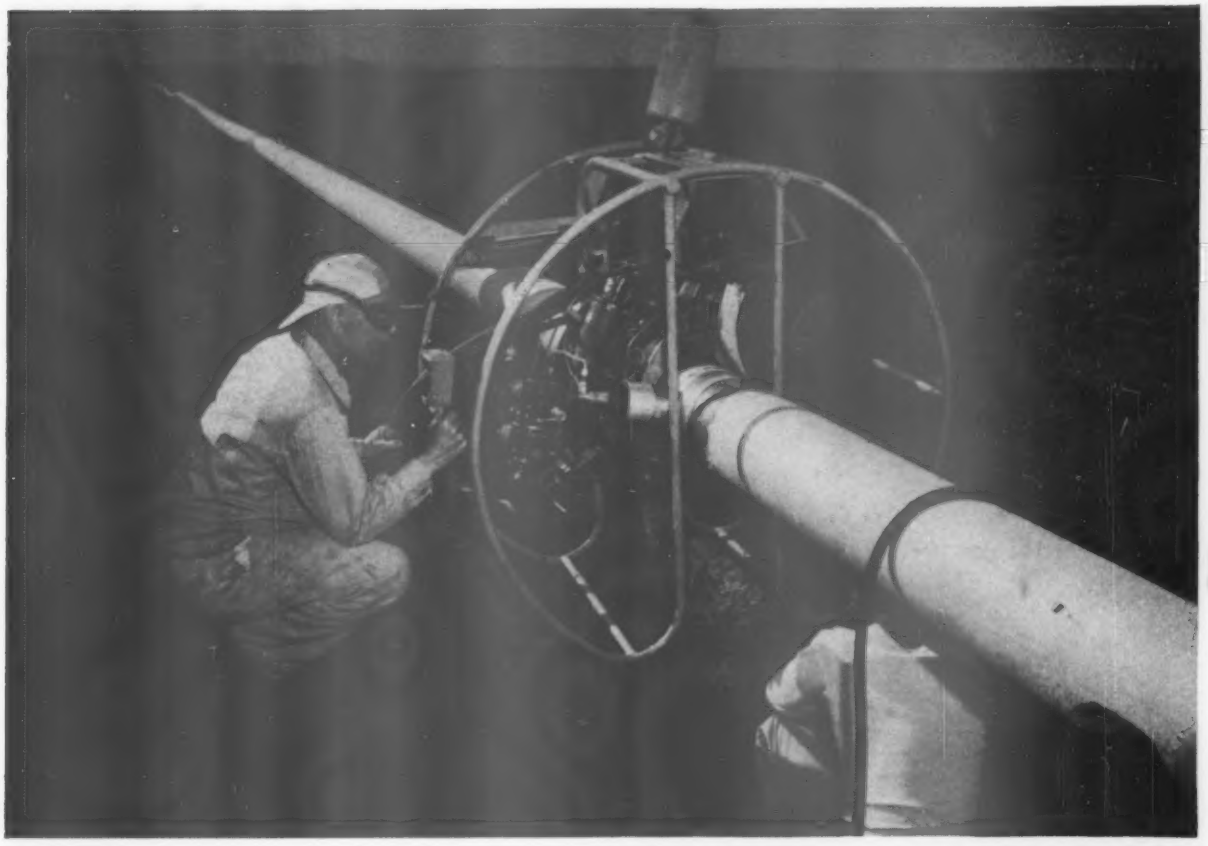


Fig. 2 This new type automatic pipe welder was developed by Reynolds Metals and Air Reduction Co. With it, pipe welds are made which will withstand 25% greater bursting pressures more than heretofore obtainable by the best standard methods

The pipe in the welding demonstration was coated with a primer and $^{3}/_{32}$ in. of bitumastic enamel. This was followed by a fiber-glass wrap and 60–70 lb Kraft paper. The binding of the coating to the aluminum pipe, Reynolds representatives showed, was unusually good. The damage often incurred in handling pipe after shop-wrapping also is minimized by the use of the lightweight aluminum.

Mr. Moore said: "The inside surface of aluminum pipe is so smooth it approaches that of glass tubing. This means much less friction and less pressure drop in aluminum lines, with consequent savings in transmission costs.

"The major advantage of aluminum over steel is the weight differential. Aluminum, which weighs about one-third as much as steel, can be used for aerial river crossings and bridge crossings where steel is impractical. This is especially important where pipe is to be attached to an existing bridge which is near weight limits."

The line being laid near Corpus Christi is the first full-scale use of the newly developed automatic welding machine. Short test lines with smaller diameter pipe were laid earlier at Listerhill, Ala., for the Alabama-Tennessee Natural Gas Co., and at Jal, N. Mex., for the El Paso Natural Gas Co. Both installations proved successful and made it possible to perfect the process.

WELDABILITY OF STEELS

An outstanding summary of current knowledge of the Weldability of Carbon & Low Alloy Steels prepared by Drs. R. D. Stout and W. D'Orville Doty under the direction of the Weldability Committee of the Welding Research Council.

Book of 381 pages including tables for welding ASTM, SAE, ABS and other specification Steels in all thicknesses.

List Price $6.50. A 20% discount to members AWS. Limited Edition. Order your copy now!

AMERICAN WELDING SOCIETY
33 West 39th St.
New York 18, N. Y.

Overhead view of the tunnel shield as it neared completion at Alco's Schenectady shops. Shown are the massive "A" and platform supporting frames, and the hydraulic jack housing, all of which make up the internal structure of the shield

Tunnel Shield Welded

THE tremendous, all-welded steel tunnel shield for the third tube of New York City's Lincoln Tunnel was completed recently at the Schenectady shops of the American Locomotive Co. Scheduled for delivery in a few weeks, the shield was inspected by officials of the Port of New York Authority and members of the contracting firm who will build the new tunnel.

The tunnel shield is the actual cutting edge which will be used to bore the new tube through the bed of the Hudson River. As sections of mud and rock are removed from in front of a shield, it will be thrust through the muck under hydraulic pressure and the cast-iron and cast-steel rings which form the lining of the tube will be erected behind the shield.

Among those who visited Schenectady were Francis Donaldson, Vice-President, and H. L. King, Chief Engineer, of the Mason & Hagar Co.; Mansell MacLean, President, and Louis Nadel, Design Engineer, of MacLean, Grove & Co.; Richard Johnson, Vice-President of the Arthur A. Johnson Co.; Arne Jacobsen, Field Superintendent of Craftsmen Welders; E. P. Pitman, Engineer of Materials and A. Thomson, Metallic Inspector of the Port of New York Authority. The group arrived in Schenectady aboard the "Empire State Express" and spent an afternoon inspecting both the tunnel shield and the general facilities of the American Locomotive Co.

A contract to build the shield was awarded to American Locomotive in July 1953. Alco has long been one

of the country's largest builders of the complicated tunnel-piercing equipment, having supplied shields for the first two tubes of the Lincoln tunnel, as well as for the Brooklyn-Battery Tunnel, the Queens Midtown Tunnel and numerous subway tunnels in New York City.

According to James Dugan in his new best seller, *The Great Iron Ship*, the first tunnel shield was designed in 1823 for construction of the Thames River Tunnel and is still in use by the East London Railway. This shield was built by a British engineer, Marc Isambard Brunel, after he watched the destructive shipworm consume the fibers in the planking of a sailing ship and pass them through his body as he moved forward through his wooden boring. Oddly enough, Mr. Brunel's tunnel shield was larger than the one built by the American Locomotive Co., measuring 38 ft in diameter and 23 ft in length.

Alco's shield weighs 240 tons and is constructed of welded steel plates and heavy steel castings. It measures 31 ft 8 in. in diameter by 18 ft 4 in. in length and is the first shield employing an all-welded steel shell and internal structure to be built.

The shield has taken Alco five months to build. It will now be dismantled into nine sections and shipped by special deep-well railroad cars to Weehawken, N. J., where preliminary work on the tunnel was started in September 1952. Contrary to many other similar projects, the entire tunnel will be driven from one side of the river.

The new $100,000,000 tunnel will be bored adjacent to the existing tubes of the Lincoln Tunnel, and is scheduled for completion in 1957. It will handle a peak load in either direction depending on the proponderant flow of traffic. The Port of New York Authority expects to increase the capacity of the Lincoln Tunnel, which handled 20,771,676 vehicles during 1953, by 50 percent when the third tube goes into operation.

Mobile Arc Welders Go Directly to Jobs

Jeeps equipped with 200-amp generators, driven from engine, do welding wherever vehicles can go. Also carry gas for cutting. Some have winch for hoist or other auxiliaries

ARC welding, whether for new construction or for repair purposes, often must be done in remote areas and in many other locations where, even if electric power lines are installed, a welding generator is not available. What is more logical, then than to equip light trucks with such generators and to provide drives for the generators from the engines of the vehicles?

Precisely this has been done by Parsons Willys Sales and Service, Washington, Pa., as the Jeeps it sells are exceptionally well adapted to jobs of this kind. These versatile vehicles can go wherever a four-wheel drive truck can go and, when properly equipped, can be ready for a variety of welding jobs almost instantly upon arrival where welding is needed. If equipped with a winch and hoist, the Jeep can lift and place the weldment or other equipment, besides doing other similar jobs to expedite and simplify construction or repair work.

By foreseeing the need for such specially equipped Jeeps and by arranging to make them available along

Fig. 1 Jeep equipped by Parsons Willys Sales & Service with an arc welder, including a generator driven by belt from the engine. An oversize exciter supplies current for lamps to facilitate use at night

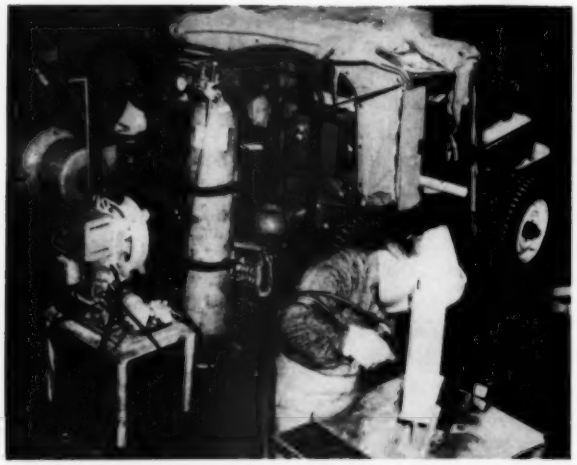


Fig. 2 This Parsons equipped jeep, including a generator and equipment for gas-shielded arc welding (especially on aluminum) is said to be one of the first mobile units to be built for work of this type

with equipment for a wide variety of needs, Parsons has helped its own sales, at the same time serving pressing demands of numerous customers. Not all of these need welders, but the Parsons service station has its own arc-welding facilities and uses them to great advantage in applying special equipment of many kinds to the Jeeps. Weldments commonly are needed for attaching and supporting the special equipment and intermediate driving units. Besides this, the equipment itself, purchased from many sources, usually involves weldments because welding generally is the most convenient and secure means of assembly.

In Fig. 1 is shown a 200-amp Lincoln generator and arc-welding control unit and a torch of the same make applied to and operated by a Jeep. Drive of the generator is by four V-belts, front power take-off. Arrangement is such that there is no interference with the regular road operation of the vehicle, which can go anywhere at a moment's notice. Included in the generator unit is an oversize exciter that furnishes current for lights that can be attached to the vehicle or placed elsewhere, which current is also used to operate electrical tools on the job and especially for night work at otherwise unlit locations.

For a Jeep thus equipped, the customer investment is less than $2500 and a winch and hoist can be added for another $500.

Welding equipment supplied is not confined to open arc welders but can include semiautomatic hidden

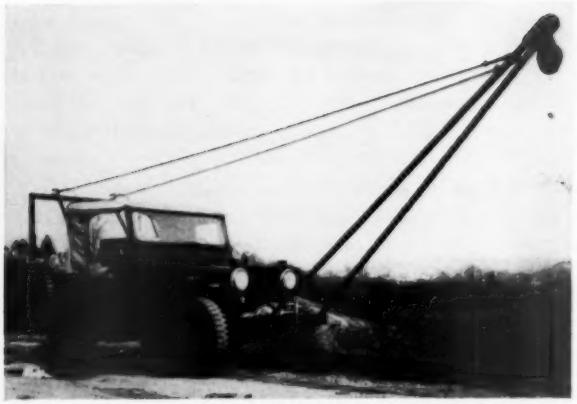


Fig. 3 Besides carrying complete arc-welding equipment, this jeep, has a motor-driven winch that operates a hoist and greatly increases the utility of the mobile unit

arc equipment or that for gas-shielded arc welding. Figure 2 shows a setup of the latter type, designed especially for welding aluminum and is believed to be the first mobile unit for aluminum welding to be built. Included is a welding generator and controls plus a tank for the shielding gas (argon or helium) and the equipment for feeding the gas at the desired controlled rate.

Besides welding aluminum, equipment like that in Fig. 2 can be used on stainless steel and on gages of carbon steel too thin for other types of arc welding. Jeeps equipped with arc welders often carry, in addition, tanks of gas for oxy-acetylene cutting and for gas welding, hence are able to do repair and construction work of a wide variety and are capable of meeting diversified conditions encountered in the field.

Figure 3 shows a Jeep supplied by Parsons with a hoist and winch in addition to welding equipment. Such a vehicle is ideal for a variety of road and off-road work partly because, in addition to doing welding jobs, it can shift and place weldments and their components and do other lifting incident to repair and construction jobs.

As Jeeps are equipped with drive on all four wheels, their use is not confined to roads. They can go almost anywhere on or off roads, over rough terrain and into locations where heavier and larger trucks cannot penetrate. When supplied with arc-welding equipment, they are amazingly versatile and are expected to extend arc welding into many places where it could not be done to advantage, if at all, before.

2500-MPH Wind Tunnel Provides Stud Welding's "Biggest" Job

Nearly 20,000 large-diameter, granular flux-filled studs are applied by split-second hand gun for compressor blade mounting. Savings effected over conventional threaded studs approach $100,000

LARGEST stud-welded assemblies ever produced are five giant compressor stators being fabricated by Westinghouse as a part of its job of constructing the world's most powerful wind tunnel, now being erected at the U. S. Air Force's Arnold Engineering Development Center, Tullahoma, Tenn. These 26- to 34-ft diam stators, when ultimately in place with rotors having 216,000 connected horsepower, will produce supersonic gales of 2500 mph and more.

Figure 1 shows "Hurricane Alley." The gigantic tunnel through which winds will howl is seen in Fig. 1 under construction. In the foreground the elliptical support will brace the corner where the tunnel turns 90 deg to the left. Although the tunnel is 55 ft wide at its largest outside diameter, the actual test section where jet engines, guided missiles and aircraft models will be tested narrows down to 16 by 16 by 40 ft long. The test section will be completely removable from the tunnel circuit so that test items may be installed or modifications made without interruption of the test program in the tunnel.

Each of the stators carries stationary blading in several rows. Each blade has a cylindrical shaft termination which is mounted in sleeve bearings housed in the stator ring, so that blades may be rotated to adjust pitch as required during operation. Each of the blade bearings is in turn mounted by means of 20 Nelson studs, giving a total of about 20,000 studs for the compressors.

The transonic compressor has $2^1/_2$- by 6-ft stator blades which weigh 1000 lb each and turn in an inner bearing mounted on the stator ring with eight $^3/_4$-in. diam studs, and against an end plate bearing utilizing a dozen $^5/_8$-in. diam studs.

The giant ring shown in Fig. 2 is one of 11 similar rings for carrying stator blades in five compressors being constructed by Westinghouse for the Air Force's new wind tunnel.

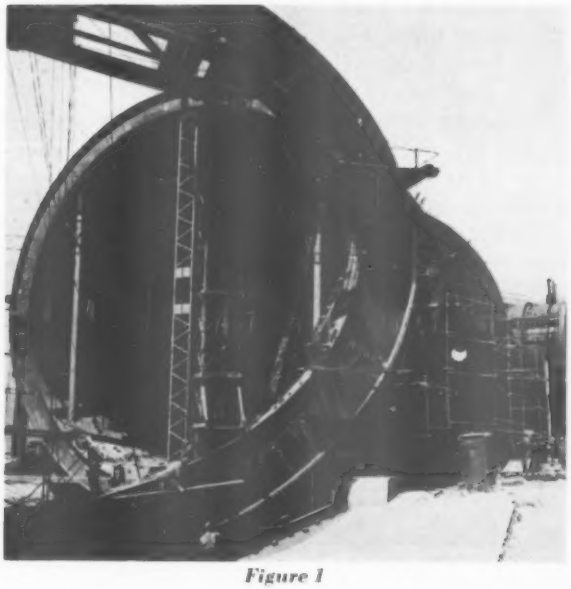


Figure 1

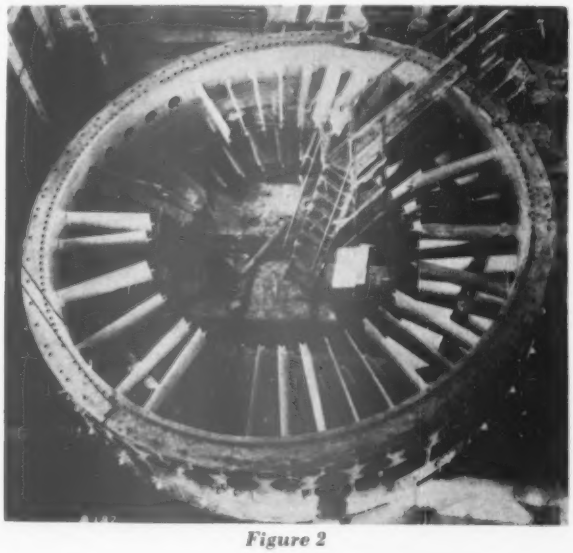


Figure 2

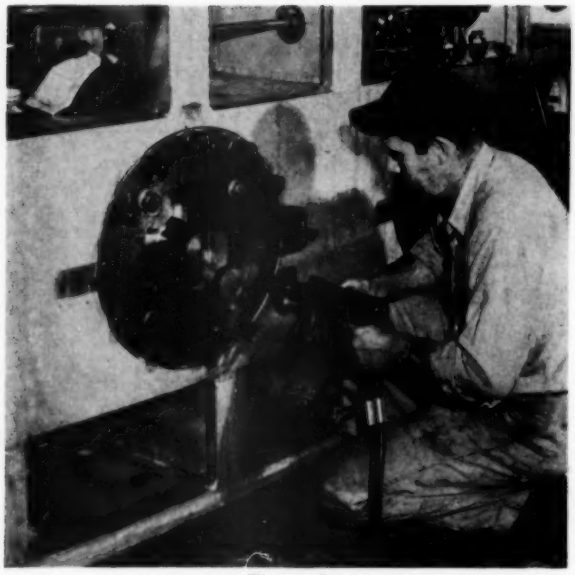


Figure 3

The large blades are mounted by means of bearings supported by granular flux-filled studs, permanently welded in place on the ring by the split-second Nelson fastening process at a saving of almost $100,000 over conventional drilled and tapped studs.

A Nelson power unit (Fig. 3) control unit and cable-connected, 5-lb hand gun makes it a matter of a trigger-squeeze to permanently end weld $^5/_8$-in. steel studs to this giant wind tunnel compressor ring.

Using a simple template to insure stud location within 0.015 in., the operator is applying 12 of the granular flux-filled studs to be used to mount the outer bearing for one of the 88 blades in the 34 ft diam by 10-ft stator ring.

The gear box to the upper left of the blade shaft (which is seen in the bearing aperture) is part of the pitch-adjusting circuit used to rotate the blades simultaneously during operation.

Each of the studs was applied at the pull of a Nelson stud welding gun's trigger, being permanently end welded in place with a weld strength exceeding the strength of the stud itself.

A simple template, positioned in the machined bearing holes in the ring frame, was used to locate each of the radially disposed studs within 0.015 in.

Savings gained in substituting stud welding for conventional studs in drilled and tapped holes are in keeping with the size of the job. Total material cost for the granular flux-filled studs was less than $2000, compared with $40,000–$50,000 which would have been required for tooling *alone* if drilling and tapping had been used.

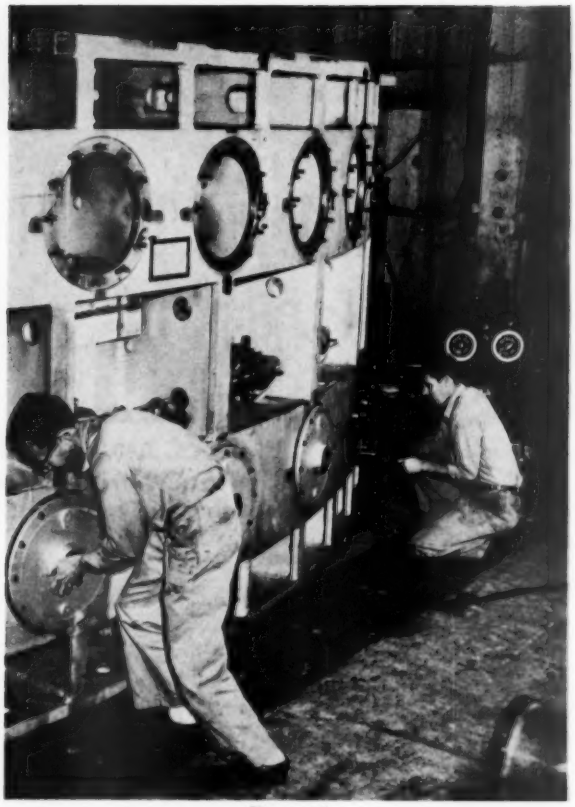


Figure 4

Cost of split-second application of the Nelson studs was likewise but a fraction of what it would have been on a long machining job had conventional studs been used. Threaded-stud specifications would have called for a Class 5 fit, which would have required drilling, reaming, rough tapping and finish hand tapping each stud hole. Pricing such holes at as much as $2.00 each, and adding the cost of broken taps to the tooling expense would bring savings effected by stud welding on this project close to $100,000.

In addition to slashing costs on the trunion mountings for the five giant compressors fabricated by Westinghouse at its Sunnyvale, Calif., plant, the Nelson stud welding process greatly speeded the work (Fig. 4).

Drilling and tapping for conventional threaded studs was completely eliminated. It was then but a 4-min process for the stud welding operator to apply the 12 outer bearing studs as shown at the right.

The Adaptation of the Semiautomatic Welder to Magnetic Flux

by R. A. Hand

AN EXTREMELY simple, inexpensive nozzle adapter for the conventional semiautomatic or "squirt" welder gives promise of a new and considerably wider use for this machine. The device makes possible the deposit of various alloys at speeds far higher than can be obtained by ordinary manual welding. In essence the process utilizes the magnetic field created by the passage of the electric current through the bare electrode, plus a magnetic alloy flux which coats the wire immediately ahead of the welding arc.

R. A. Hand, Automatic Welding Specialist, Stoody Co., Whittier, Calif.

The operating cycle is completed by the use of permanent magnets in the nozzle adapter which act as a dam to the flow of flux whenever the arc is broken.

The whole process is merely a combination of two accepted and proved welding methods—the squirt welder which uses a granular nonmagnetic flux to produce the common submerged melt deposit, and the magnetic flux method of automatic welding as perfected by Brown Boveri in Switzerland some years ago. The squirt welder, employing the hidden arc beneath a simple flux, is in everyday use and is familiar of course to all those interested in welding.

The Brown Boveri method is less widely recognized. Basically it depends upon use of the magnetic field surrounding the welding electrode in conjunction with a granular magnetic metallic flux. In this machine the flux in the standard hopper is fed by gravity to a cup around the contact jaws. Thus, when the arc is established the magnetic lines of force cause the flux to adhere to the wire, producing what is to all intents and purposes a coated electrode. The amount of flux applied to the wire is governed by the size of the orifice in the cup. In the Brown Boveri equipment an electromagnetic coil in the cup acts as a dam when welding is interrupted. This general process was covered by European patents some eight years ago and has been used since then for mild steel fabrication much as the submerged melt process has been employed.

Some time ago Stoody Co. became interested in magnetic flux as a possible method of applying alloy materials through semiautomatic welders, the use

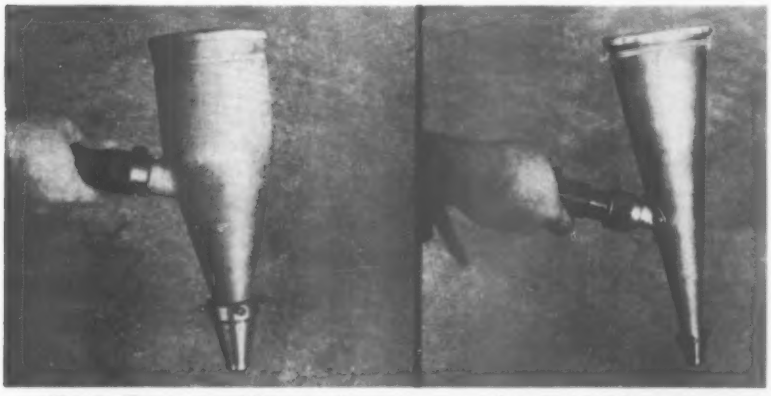


Fig. 1 Two types of hoppers in common use fitted with adapter tips

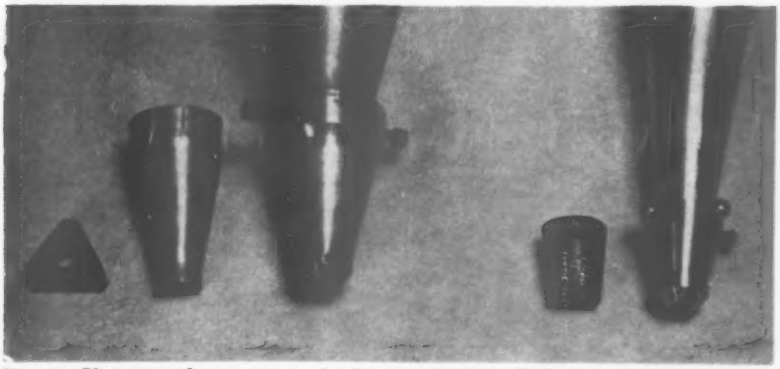


Fig. 2 Close-up of two types of adapter tips installed on standard hoppers; original tip shown with each

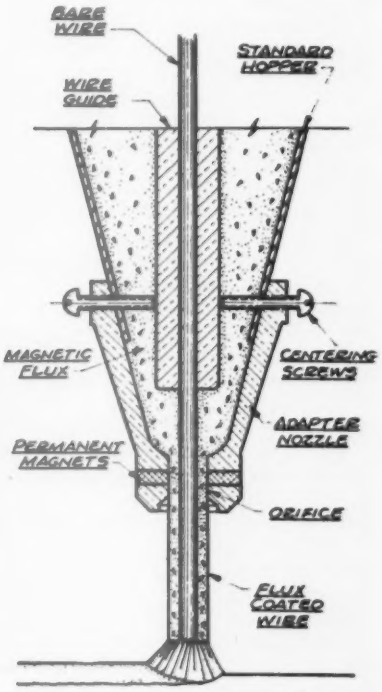


Fig. 3 Cross section through adapter nozzle

of which is limited to small diameter wires, generally 5/64 and 3/32 in., sizes too small to be fabricated into tubular wires such as this company furnishes for application through the full automatic head. The Brown Boveri method, as adapted to the squirt welder and tested over a considerable period, appears to offer numerous advantages over both manual and present semiautomatic welding. As applied to build-up and hard-facing, the magnetic process provides much higher deposition rates (8 to 20 lb of deposited metal per hour, using 5/64- or 3/32 wires); the deposition rate will depend upon amperage. Deposits are sound, with the consistency and uniformity characteristic of the automatic welding method. Time lost in changing electrodes is eliminated and there is of course no stub-end loss. There is no need for maintaining large stocks of various electrode diameters. Welding time and material costs are shown to be markedly reduced.

By comparison with the semiautomatic hard-facing method utilizing an alloy submerged melt flux, the magnetic process eliminates considerable waste, since all the flux applied to the wire is consumed. An important consideration is the fact that with the magnetic process the welder is using an open arc which allows him to see the actual welding at all times, gives him better control of the deposit and permits the hard-facing of irregularly shaped parts. While the conventional hopper is of small size for ease of handling, it is necessary to refill it only infrequently, since the ratio of deposited metal to flux used is approximately equal.

The squirt welders now in common use may all be readily adapted to operate with magnetic alloy flux. The photographs and sketch show clearly how easily the adaptation is made. The adapter tip containing the permanent magnets replaces the standard tip, centers the wire to assure a concentric flux coating and governs the amount of flux applied to the wire.

How to Build a Television Stand

by Guthrie B. Stone

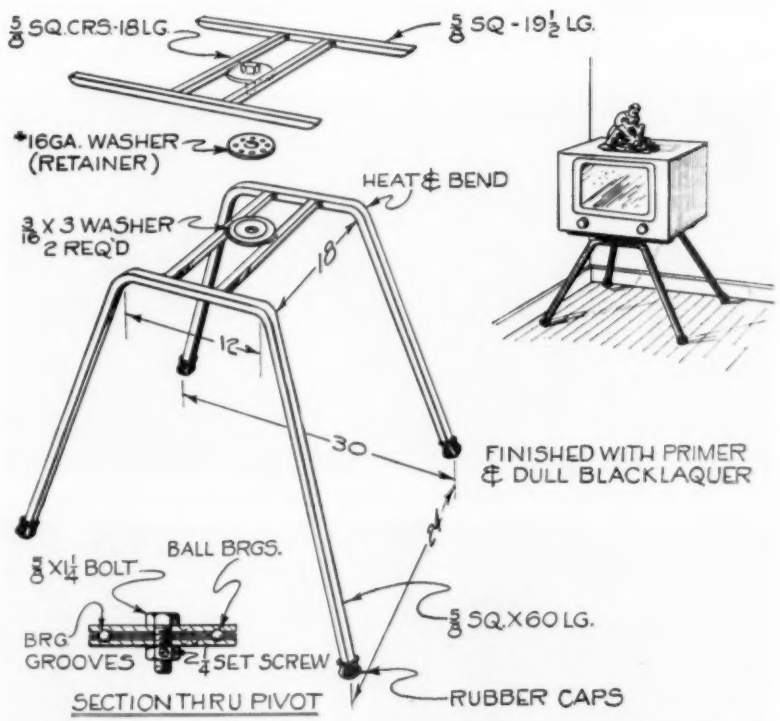
HERE is a rotatable television stand. With simplicity foremost in mind, I have used 5/8-in. square, cold-rolled 1018 steel bar welded together with LH-70 to form the stand.

First, the two leg pieces are heated and bent to shape and checked for uniformity. When setting up, I did so with legs up and welded in the two cross pieces which are also of 5/8-in. cold-rolled, 18 in. long. The upper table was made for a 17-in. model but will fit others. Other welders may want to vary this size to suit their individual set.

The swivel thrust gearing is made up of two 3-in. OD washers with a 5/8-in. hole, 3/16 in. thick. These can be bought or made from hot-rolled plate. A groove is cut in on a lathe to form races for the 1/4-in. ball bearings, leaving clearances and space for 16 gage sheet, drilled with 1/4-in. holes, which hold eight ball bearings in position.

If a lathe is not available, the two washers alone will make a good suitable thrust bearing.

The center pin consists of one 5/8 x 1 1/4-in. SAE bolt with the nut drilled and tapped to take 1/4-in. setscrew. After adjusting the bearing so it turns freely without any extra play the setscrew is locked on the threads.



Lubricate with a small amount of vaseline before assembly.

Costing 10¢ each, the rubber leg cups are smaller but similar to those you see on crutches. Although round, they will fit tightly over the 5/8-in. square rod.

After sanding welds and rough spots, I finished with one coat of primer and one coat of dull black lacquer. Total cost of materials including paint was approximately $4.85. Total labor time was two hours. Cold-rolled steel was selected for its extra rigidity, thus enabling the use of a smaller size square and resultant thinner lines in the over-all appearance.

Guthrie B. Stone, Honeoye, N. Y.

This suggestion won the "Stabilizer" award for the month.

New Spot-Welding Method Reapplies Stainless Steel Car Sidings

CAR repairmen on the New York Central Railroad recently demonstrated the spirit which helps keep their rolling stock in tip-top condition, after they examined a number of streamlined passenger cars which had been in service for several years. Although the cars still were able to give good service, the repairmen decided that their stainless steel exteriors should be renovated.

One hundred and fifty of these cars are now undergoing a change at the railroad's Beech Grove, Ind., shops. Their fluted sidings are stripped off, cleaned and then spot welded to the cars. Reconditioning begins by removing the sidings as carefully as possible to prevent any damage. Reclaimable strips are cleaned at the weld area by a specially constructed machine, shown in Fig. 1. Strips are propelled at high speed between two wire brushes which thoroughly clean them on both sides.

These 70-ft long pieces are placed on a $^{3}/_{4}$-in.-cambered table and assembled. Seven strips are required for the lower section of the car, four strips for the section above the windows. Spot welding is started at one end to hold the pieces together, as in Fig. 2, followed by a number of spot welds spaced in the middle of the section and then at the other end. The complete section is thus held in place. Spot welds are then made in the remaining spaces. This procedure is also used in assembling the top section of siding. See Fig. 3. A bottom section requires 1550 spot welds while the top section needs 980 spot welds.

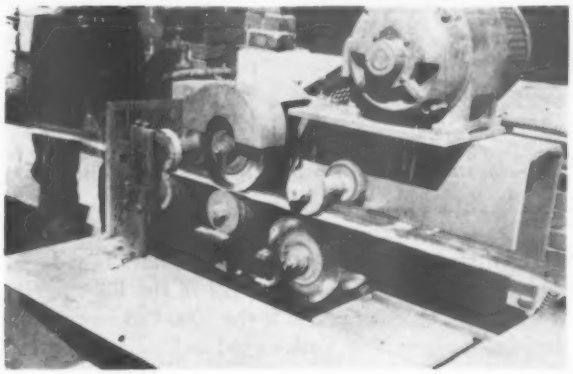


Fig. 1 This specially constructed machine employs two wire brushes which clean both sides of stainless steel fluted strips for reapplication as sidings on streamlined passenger cars

New $^{1}/_{16}$-in. stainless steel channels are are welded to the sides of the car. The car sides are sandblasted and prime-coated in preparation for the sheathing, as in Fig. 4.

Assembled sections of welded sidings are then placed in position on the car. Figure 5 shows one man operating a lever which holds the siding in place while another man spot welds the stainless steel sheathing to the channels. The entire bottom section requires 300 spot welds in this operation, while the narrower top piece needs 225.

Following the application of the stainless steel fluted siding to the car, lengths of $^{3}/_{16}$-in. snap-on moldings are put into place, covering the welded seams. The completed car shown in Fig. 6 is now ready for final polishing.

Fig. 2 Stainless steel fluted strips for the bottom section of the car side are welded together with the use of the "Heliarc" HW-8 spot-welding gun

Fig. 3 The spot welder is used here to join the stainless steel strips that will cover the car side above the windows. Welding is done on a bench cambered 3/4 in.

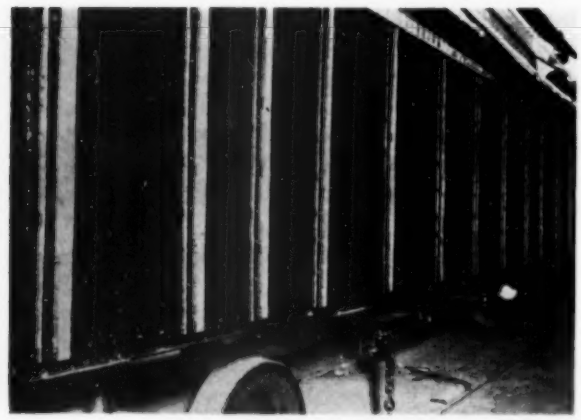


Fig. 4 Stainless steel 1/16-in. channels are arc welded to the sides of the car. The sides are sandblasted and prime-coated before the fluted sidings are welded to the channels

Spot welds are made with the "Heliarc" HW-8 torch using 1/8-in. electrode. D-C settings for spot welding are set according to manufacturer's recommendations. Shielding argon flows at 25 cfs. About 2 cylinders of argon are used for 3 cars. Both sidings and channels are 18–8 stainless steel.

These cars return to service on the New York Central R. R. with no obvious change in appearance, but their few days in the Beech Grove shops have added extra years to their lives of usefulness.

Fig. 5 Two men are able to apply the prewelded section to the bottom of the car. One man operates a lever which holds the strip in position while the welder uses the HW-8 torch to spot weld the strip to the channels

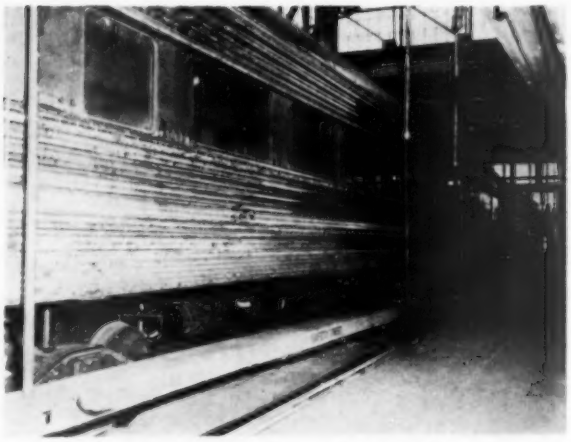


Fig. 6 This passenger car has had its stainless steel siding reapplied and is ready for a thorough polishing before it graces the tracks of the New York Central Railroad

Welding Giant Sheaves

THREE steelmaking processes—forging, rolling and welding—played a part in the manufacture by Bethlehem Steel Co. of four giant sheaves for the new $6,000,000 vertical-lift bridge to Welfare Island, N. Y.

The three-lane bridge, connecting Welfare Island and Queens, will span the east channel of the East River. It will afford speedier access to the 7000-bed hospital on the island, where New York's aged and infirm are cared for.

Automobiles now reach Welfare Island by elevators from the Queensboro Bridge. The cumbersome

elevators frequently cause traffic jams on the bridge when lines of automobiles form near the easterly end while waiting to be lowered to the island. This congestion has hampered the increasing vehicular flow over the Queensboro Bridge between Queens and Manhattan.

Over the sheaves, after they are placed in the towers of the new bridge, will pass cables carrying the 515-ton counterweights. The total weight of the two counterweights will approximate the weight of the lift span.

Weighing 37 tons apiece, the sheaves are about 15 ft in diameter. Their hubs were forged on a 2500-ton forging press and center-bored to an inside diameter of 22 in. at the Bethlehem, Pa., plant of the steel company.

For the web section, two rolled plates, $1^3/_4$ in. thick and 7 ft 3 in. wide, were welded together and the cutouts were made. Stiffener ribs of plate of the same thickness were welded inside the web to give it added strength. The plates, as well as the rims of the sheaves, were rolled at Bethlehem's Sparrows Point, Md., plant. The rims are rolled plate 6 in. thick and about 3 ft wide. Following shipment to the Bethlehem, Pa., plant, the rims were cold formed into semicircular shape and butt welded together to form a complete circle.

Then the web plates, with backing strips, were welded to the hub and the rim. Both the hub and the rim were preheated with gas burners to a minimum of 200 deg and maintained at that temperature during welding to minimize cooling strains after welding. About 275 lb of weld metal was used to fill the gap between the web and the rim.

Figure 1

The pipe burner used to preheat the rim was made specially for the occasion. The burner comprises two semicircular pieces of 3-in. diam pipe with two rows of holes for gas jets. The two halves of the burner were placed around the periphery of the rim and lighted.

After welding, the sheaves were heat treated to relieve any stress set up in the welding process. The sheaves then moved to a machine shop for finish machining and the cutting in the rim of 12 cable grooves, which are about $2^1/_2$ in. wide, to hold the counterweight cables.

Heavy Wall Pipe Welded Direct to Thin Wall Pipe

◗ *New system used on Gulf Interstate Gas Co. line*

THE 860 Mile Gulf Interstate Gas Co. Line, from the Coast of Louisiana into West Virginia, used a new welding system at all highway, railroad and river crossings where $^3/_8$-in. wall X-52 pipe is joined to $^1/_2$-in. wall X-52 pipe.

This new type of weld preparation eliminates the use of a "transition piece" allowing one weld to take the place of two, and permitting greater distance between welds in keeping with best welding practices. Field machining of the $^1/_2$-in. wall pipe with the New Inside Beveling Attachment, for the Wachs National Pipe Saw, makes this single type weld possible.

The $^1/_2$-in. wall pipe was double or triple joint welded into lengths required for crossings. Test plugs were

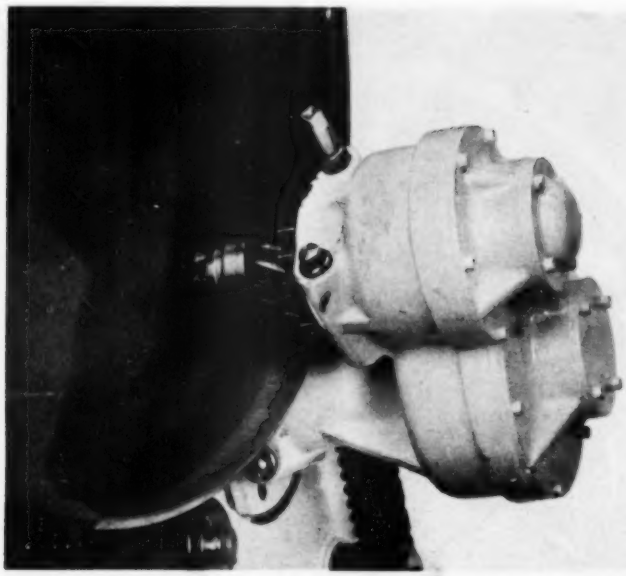


Fig. 1 Close-up view of internal beveling attachment on Wachs National Pipe Saw cutting an internal bevel on an X-52, 30-in. diam steel pipe. Note that the internal bevel attachment is now "thinning down" the inside to make a transition from $^1/_2$-in. wall to $^3/_8$-in. wall pipe

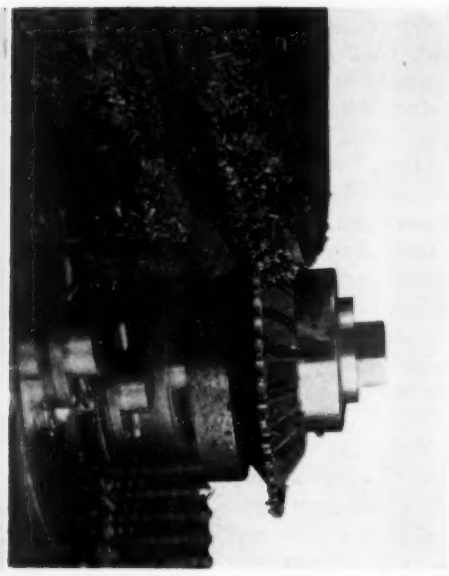


Fig. 2 Close-up view of external bevel cutter on Wachs National Pipe Saw cutting and beveling X-52, 30-in. diam steel pipe

then welded on the ends and an 8-hr hydrostatic test was run on every crossing section. This necessitated cutting the test plugs off of the heavy wall pipe at completion of the hydrostatic tests. A standard saw and external bevel cutter were used. This cut and bevel were made in one operation. At the completion of this cut the New Wachs Internal Beveling Attachment was placed on the basic saw unit and an internal bevel machined to reduce the $^1/_2$-in. pipe down to proper welding thickness for $^3/_8$-in. wall pipe. This results in a "machine shop" bevel (inside and outside) ready for welding with no change in the physical properties of the pipe.

The saw with the new inside beveling attachment is being used in the construction of the Gulf Interstate Gas Co. Line by the H. C. Price Co. and the Houston Contracting Co.

Fig. 3 A Wachs National Pipe Saw with internal beveling attachment machining a bevel on the inside of $^1/_2$-in. wall, 30-in. diam, X-52 pipe. The inside is being thinned down to allow welding to $^3/_8$-in. wall line pipe

Fig. 4 A Wachs National Pipe Saw cutting and beveling $^1/_2$-in. wall, 30-in. diam, X-52 pipe. Note that the test plug is being cut off the end of 30-in. road crossing pipe upon completion of the hydrostatic test

the AMERICAN WELDING SOCIETY
activities • related events

Welding in Today's and Tomorrow's Worlds

By Fred L. Plummer, President, American Welding Society

Tomorrow in the Memorial Auditorium of this gracious host city of Buffalo, our Welding Industry and our SOCIETY join in opening to all the Second National All-Welding Show. Under one roof and on one level, there will be assembled every type of arc, gas, resistance and combined process—welding machine, equipment and apparatus. Through exposition and demonstration, we will show the designer and the purchasing director, the plant executive and the engineer, the metallurgist and the welder, the buyer and the user how modern welding, brazing, cutting, heating and surface-treating process can save industrial fabricators thousands of dollars annually; can produce products having reduced weight, greater strength, superior quality and lower unit cost; products which possess the smooth lines and pleasing contours attainable only through welding; products with the "eye appeal" which creates "buyer appeal."

At the Welding Show, and at the technical meetings here in the Statler Hotel, fabricators of metal assemblies will learn how, with the most recently developed welding apparatus, equipment and machines, and using modern welding and allied process procedures, they can advantageously effect labor, material and time savings, materially increase their production, substantially reduce rejections and waste, appreciably lower their maintenance costs, and do so with greater safety.

The bringing of these all-welding shows and spring technical meetings to strategic centers of our country's fast expanding industrial empire is but one of many ways in which your SOCIETY and Industry diligently strive to serve today's industrial and welding world, and to assist in the building of our world of tomorrow.

Comprehensive research in any field of industrial production and sales activity will disclose that if, in 1925, 1900, 1875 or at the termination of any previous 25-year period, progress and expansion during a quarter century had been completely charted, the expectancy curve of advancement for the next 25 years could have been predicted with reasonable accuracy, despite unpredictable wars and their trailing recessions. Therefore, as of today, the necromantic powers of a prophet are not required for predicting, with comparable accuracy, the extent of progress, new development and expansion we may anticipate within the coming quarter century.

Let us turn a deaf ear to those mongers of gloom who spread the insidious words "poor business," "recession" or "retrenchment." We are not in a recession period. The contrary is the truth. We have but recently stepped down from a high ladder of war activity. While on it we were forced to carry upon our shoulders the unnatural load of war production. We have unburdened ourselves of excess weight, shifted our gears, balanced our inventories and adjusted our sights for providing the immense volume of materials and products which will be required in a peacetime economy, and for which there is now a huge pent-up demand—and will be an ever-growing market.

The truth is that, today, we are enjoying the experience of having mounted the first step of an upgoing escalator; the first stage of a peacetime boom which may be far greater than any this land of ours has ever known.

Whether you are fabricators, producers of finished consumer products or manufacturers of welding machines and equipment, we suggest that you look back to 1925! Check the steel tonnage output, a reliable barometer for your output and sales that year. Check the number of automobiles produced in 1925; the volumes of coal, oil or electric power consumed by industry—additional reliable indices. Check the carloads of industrial products hauled by our national carriers—and international as well—all made by American manufacturers and sold to American and international users. Check the tonnage of mechanized farm equipment produced in 1925; the volume of welding machines, equipment, gases, supplies and welding rods or electrodes sold that year. Check the amount of dollars in savings institutions and in public investments in ratio to this country's population for 1925. And finally, check the U. S. census figures and industrial and economic indices for that year—1925! Then, check all of the same for today!

But, let us not use 1953, a year of artificial war inflation. Nor 1952, nor 1951! Let us hold to our 25-year cycle and check our volumes of 1950 against those of 1925. Each sales record will vary, but all will show that your volume during that quarter century increased many, and in many instances many-many, times; even though during that same period, we experienced the greatest business depression and the most disastrous war the world has ever known!

Can there be anyone of you who doubts that welding in tomorrow's world will progress and expand within the next 25 years at least as much as it did in the previous comparable period?

Even if, in the next quarter century, all invention should cease, no new developments take place, nor one improvement in industrial products or procedures be made we could not prevent our industries from expanding, our production volume from enlarging, and our sales from increasing!

Just to meet the needs of our increasing population alone we must produce millions of appliances, thousands of miles of additional highways, hundreds of new bridges, several million new homes, millions of tons of communications facilities, millions of radio and television sets, many hundred thousand tons of air conditioning equipment, several hundred thousand motor trucks and rail freight cars, thousands of public office, hotel, entertainment, sport, school and community structures, a hundred thousand units of mechanized farm machines, thousands of miles of pipe lines, several hundred thousand airplanes, and millions of tons of armament products for protecting ourselves and the free world. To produce all this will require that we construct millions of square feet of new

Presented at the AWS National Dinner on May 4, 1954, at the Hotel Statler, Buffalo, N. Y., on the occasion of the AWS National Spring Meeting and Welding Exposition.

ALLOYS
All-State
FLUXES

WE'VE GOT TIME ANYTIME TO TRY TO SOLVE YOUR PROBLEM

Welding people have been tossing problems to us for years now. We like it. And, we've successfully found good answers to so many of them that today we can offer you off the shelf:

The world's most complete line of alloys and fluxes for aluminum,

8 alloys and fluxes for work on cast iron,

12 for copper, brass, etc.,

8 for stainless steel,

12 for steel,

Many other alloys and fluxes for magnesium, nickel, zinc-base die cast, tinning, galvanizing, cutting, bevelling, and chamfering

Chances are that we can give you your answer quickly.

Or, perhaps you can find it yourself in our 24-page Buyers Guide.

Showed me how to join nichrome to copper.
Made me the world's strongest soft solder.
Gave me an electrode a beginner can use.
Showed me how to repair heat treated parts without spoiling the temper.

Want a copy? Ask...

ALL-STATE WELDING ALLOYS CO., INC.
249-55 FERRIS AVE., WHITE PLAINS, NEW YORK

DISTRIBUTORS EVERYWHERE

industrial plants! And all of this is but what we will need just to provide for our increasing population!

But, in the history of America has there ever been a period when we were satisfied with the status quo? Has there been a decade, a year, a month, a week, or a day when advancement, improvement or progress of some character was not our pattern of life? Have we ever lacked for new ideas, new inventions? Have we, at any time, held with things that were old, rather than replace them with those that were new? All here know the answers to these questions. We are blessed in that we are a vigorous, impatient people, ever seeking ways, means and things which will help to improve our way of life.

Added to the needs of a fast-growing population will be the demand for products still not conceived, let alone produced; replacement of equipment—modern today, but obsolete in tomorrow's world because of the inevitable improvements that will take place in every process, procedure and activity which we now know.

Within the past 25-year cycle, new metals, formerly precious, were produced in unbelievable volume and at competitive cost. Today, they are of common use—and are welded. New alloys, once rare, were produced in substantial quantities, making possible their economical use for vastly improving our steels. Can we believe that as of today we have reached the end of metallurgical exploration, and that the coming quarter century will be devoid of at least comparable progress? We cannot stop our advancement in so short a period. Like the power behind any driving force, the momentum we have created will carry us onward even were we to attempt to halt!

Standing on the threshold of tomorrow's world we face, within the next quarter century, the task of converting our entire industrial activity to the pattern of atomic energy. In an effort to describe the potentials we find superlatives such as "tremendous" and "stupendous" to be quite inadequate. Consider a single and simple example. Since the first atomic development took place at the University of Chicago, thousands of miles of welding—I repeat—thousands of miles of welding—have been laid in the building of the reactors and their housings alone!

Now that we are developing our atomic stockpiles to a safe volume, and our nuclear energy production facilities to an extent permitting the gradual introduction and utilization of an appreciable volume of this limitless energy for industrial motivation and power, think of the gargantuan task confronting both general industry and our welding industry as well; and of the unparalleled incentive we are given to improve our procedures and our products; and to scale steeply upward our productive capacities for meeting the demands of the coming quarter century.

In the past quarter century, welding has come of age. No longer is it "something new." Not so long ago when industry desired to present its case to the public in the advertising pages of institutional and news publications, it symbolized its activities by illustrations of the machinist or the riveter at his task. That is changing! Leaf through the advertising pages of today's institutional, industrial and news publications. Few indeed are the illustrations of the riveter or the machinist. In the majority, the greater majority by far, he has been replaced by the welder; the symbol of modern industry. Welding is accepted. Welding is the logical, the economical, the modern process for joining metals. Welding is not merely an important "wheel" in industry. Welding makes the wheels of industry. If, on this day, all welding should cease, practically all industry dependent upon mechanical operation, production or maintenance would come to a standstill within 90 days!

Less than 40 years ago, welding was a process used principally in the blacksmith shop. Today, without exception, every metal fabricating industry uses welding. Yet it is difficult to realize that this universal application of welding has occurred in only the last ten years. Today, when a new metal is discovered, or a new alloy developed, one of the first questions concerns its weldability.

Electrode production for arc welding has increased about five and one-half times since 1936. Resistance-welding machine sales have jumped to more than nine times their 1939 level. Oxygen sales have risen from 100 million cubic feet 40 years ago, to 23 billion in 1953, while acetylene in the same period rose from 121 million to more than six billion cubic feet.

The total amount spent for welding equipment and supplies in 1953 was almost $614,000,000.

Even more impressive, however, is welding's role in the future. As American industry stands on the brink of a new production revolution, that of automation, welding will play a key role. Only welding can join metal parts in the continuous and high-speed processes which automation demands. Equipment is already in use in the automotive industry which can make 30,000 welds an hour and the end is not in sight.

Looking back, we cannot be other than greatly enthused by the advancements made, deeply impressed by the number of obstacles surmounted and genuinely astonished by the degree of perfection attained. With this record of past accomplishments, how can we have other than the deepest faith in our future? With complete confidence in our ability to perform the tasks ahead, we welcome the opportunities which stretch across the horizon of tomorrow's world.

A NEW INVENTION

THE greatest development in cylinder manifold design and construction in over four decades.

Now you can assemble a cylinder manifold right on the job, without special tools; it can be shipped in ordinary boxes and put together with the ease expected of a modern "erector set." All parts fit snugly, leakproof and assure accurate over-all dimensions.

And—when desirable, the manifold may be expanded to meet increased gas capacity or you can take it apart for removal or storage; the newly invented "differential thread" joint makes all of these long hoped for qualities a reality.

NOW—you are the doctor; you may design and assemble cylinder manifolds to meet YOUR NEEDS and SPACE REQUIREMENTS RIGHT ON THE JOB—and your cylinder manifold will never become obsolescent or inadequate. YOU CAN EXTEND IT AT YOUR WILL. GET THE FACTS . . . WRITE TODAY . . . GET THIS EXCITING NEWS ABOUT A REALLY GREAT IMPROVEMENT IN CYLINDER MANIFOLD DESIGN AND ASSEMBLY METHOD.

DEALERS AND DISTRIBUTORS NOTE: now you can carry IN STOCK all of the parts needed for any size or type of cylinder manifold . . . no loss of orders because you must await a factory shipment. Why not write today for full information—it's worth your time.

Made by National SINCE 1910 WELDING EQUIPMENT CO., San Francisco 5, California

831

Cleveland Section History*

By J. F. Maine

Welding as a process of joining materials together has been changed materially over the past decade and a half. Prior to World War I, almost all welding was done by the clever blacksmith working before his anvil hammering two pieces of heated material together. Arc welding had made some progress, but had not reached the position of being considered a major method of joining materials.

The advent of the First World War, with its demand for ships and more ships, gave electric and gas welding the opportunity to show what important tools they were.

The Emergency Fleet Corp., U. S. Shipping Board, organized a Welding Committee. This Committee was charged with the speeding up of ship construction through the use of welding. The AMERICAN WELDING SOCIETY, an outgrowth of this Committee, was founded on the basis of a Constitution adopted Mar. 27, 1919, and received its Certificate of Incorporation Feb. 3, 1932. The Cleveland Section of this SOCIETY was organized Mar. 25, 1921. Philadelphia, Pittsburgh, Chicago and New York were brought in existence about the same time. The record shows Cleveland Section's first officers to be: *Chairman*, W. E. Irish, Hydraulic Pressed Steel Co.; *1st Vice-Chairman*, E. Gruber, Cleveland Tractor Co.; *2nd Vice-Chairman*, C. H. Draper, Draper Mfg. Co.; *Secretary*, Henry Spero, F. W. King Optical Co. There was also a 12-man executive committee.

There is no record of where the first meeting was held, but it is recorded that there was a meeting in December 1921 at the Cleveland Engineering Society with an attendance of 41 members. The Section in its early days had no regular meeting place, but assembled wherever there was an empty room. They met in restaurants, office buildings, Carnegie Hall, Cleveland Club, Fenn College, Midday Club and when the Cleveland Engineering Society had completed its new home, the Cleveland Section accepted their invitation to meet there. During the last several years, meetings have been held in the Hotel Allerton.

The Section has had a steady growth over these 33 years until now it is the second largest in the AMERICAN WELDING SOCIETY's large family. Its present membership is 519. Incidently, the AMERICAN WELDING SOCIETY has grown until it now has 68 sections throughout this country and Canada.

The early meetings of the Section were given over to lectures on welding followed by a discussion. Some plant visitations were also held—one as early as 1924. This same pattern is followed today.

It soon became apparent that an educational program was desirable with the result that the first educational course of record was held in 1930. This proved so successful that an educational program has been in effect every year. These courses have been held at various places such as Fenn College, Case School of Applied Science, The John Huntington Polytechnic Institute and at plants specializing in some form of welding. These courses have come to be regarded as a very important part of the Section's activities.

May 3, 1940, saw the birth of the Section's first symposium. Meetings were held during the afternoon and evening at the Hotel Statler with a banquet between the afternoon and evening sessions; 192 persons were present. Dr. J. C. Hodge, one of the Section's own members, was the speaker for the evening. A symposium has been held every year since, with an ever-increasing number of people attending. Last year 575 were served at the banquet.

The Section, through its committees, has endeavored to be helpful wherever called upon to solve the various problems concerning welding. They have materially aided the City of Cleveland in formulating its new Building Code, inserting the entire section on the welding of structural steel for buildings. They have also worked with the Building Trades Unions so that they can provide registered certified welders. Standards were also drawn covering welding for use in fabricating plants.

The list of members contains the names of many men who have contributed much for the development of welding as an important method of fabricating buildings, bridges, boilers, ships and many other ferrous and nonferrous articles used in our every-day lines. We stand ready to advise and otherwise help those having welding problems. The Section doors are always open to everyone.

* Published in the Cleveland Section Symposium Program.

CAN YOU WELD MANGANESE...
with your eyes shut?
YOU CAN – if you use...
MANGANAL
U.S. Patents 1,876,758—1,947,167—2,021,945
FLO-KOTE
11%-13½% MANGANESE-NICKEL STEEL
AC-DC WELDING ELECTRODES
Gives you all the advantages of tough, ductile Manganese-Nickel Steel weld deposits yet runs as easily as stainless or mild steel electrodes.
Not a composite rod.
Alloys in rod, not coating.
Contains Nickel, not substitutes.
Write for literature.
STULZ-SICKLES CO.
NEAREST DISTRIBUTOR UPON REQUEST
SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.

Executive Committee Meeting

The first 1953–54 Executive Committee Meeting of the AMERICAN WELDING SOCIETY was held in the Engineering Societies Building, New York, on March 23rd, at 10:00 A.M. Present were: Chairman F. L. Plummer, J. J. Chyle, J. H. Humberstone, I. Morrison, H. W. Pierce; Guests—J. F. Lincoln and J.Mortimer; and Staff Members—Secretary J. G. Magrath and Asst. Secretary F. J. Mooney.

The Executive Committee considered reports of the National Nominating Committee, New York Welding Clinic, and the 1955 AWS Exposition.

Satisfactory progress was made in extending the duration of terms of officers from October 1955 to May 1956. This will

eventually allow the National Meeting to be held in the Spring instead of the Fall.

Progress was reported on plans for improving the Technical Services and Organization Committee of the Society.

Other activities that were reviewed included the AWS-IIW relationship, the possibility of other Societies meeting at the same time as the Welding Exposition, and the establishment of a Student Chapter at the California State Polytechnic College.

Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes

Here, for the first time, are specifications covering stainless steel filler metals for use with the inert-gas metal-arc process. These latest specifications, issued jointly by the AWS and ASTM (AWS Designation A5.9; ASTM Designation A371), include corrosion-resisting chromium and chromium-nickel steel welding rods and bare electrodes. The rods are for use with the atomic hydrogen and inert-gas metal-arc (nonconsumable electrode) welding processes. The bare electrodes are used with the submerged-arc and inert-gas metal-arc (consumable electrode) welding processes.

Thirteen classifications of filler metal are established by these specifications, including all the commonly used materials. This involves, among others, the 18–8, 25–12 and 25–20 chromium-nickel steels as well as the 5, 12 and 16% straight chromium steels.

A table gives the chemical analysis of the different classifications for verifying conformity of a given filler metal to the standard requirements. Standard sizes and lengths and packaging requirements are also provided.

An Appendix is included as an aid to users in selecting the most suitable filler metal for their needs. It provides information on the use of each classification for joining different base metals with the different welding processes.

Copies of the Specifications can be obtained at 25 cents each from AWS Headquarters, 33 W. 39th St., New York 18, N. Y.

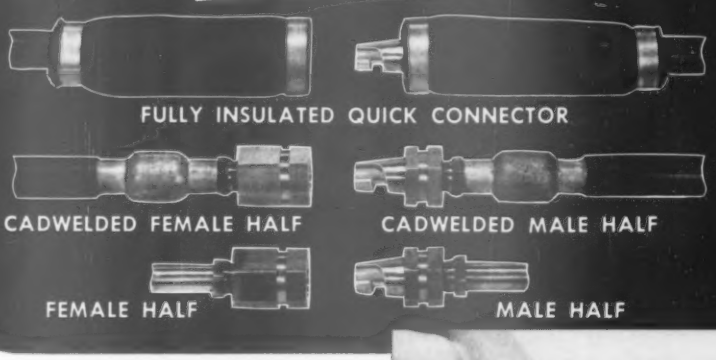
DISTRICT DIRECTORS

The names and biographical sketches of the nominees for District Directors will appear in the July issue of the Welding Journal.

CADDY®

TAPER-LOK QUICK CONNECTOR

a positive locking connector featuring the Cadweld connection—plus durable rubber insulators anchored to the welding cable.



FEATURES

1. CADWELDED CONNECTIONS	1. Permanent connections 2. High Conductivity 3. Cool Operation
2. Positive wedging action	1. Greater current capacity due to high pressure contact between connector surfaces
3. Positive locking action	1. Cannot pull apart in service 2. Easily disconnected
4. Durable rubber insulation	1. Not damaged by impact 2. No possibility of arcing 3. Any size welding cable can be used
5. Insulation Punch-Lok banding method	1. Prevents cable insulation "creeping" and pulling out of connector insulation 2. Prevents flexing at the connection
6. Female end (hot line) protection	1. Prevents arcing when male is disconnected
7. 500 Amp. Capacity	1. Suitable for all type operating conditions
8. Able to withstand vertical or horizontal pull	1. Punch-Lok hose banded grip on cable insulation and quick connector halves
9. Replaceable stud	1. Saves money when replacing old or broken cable

- Quick Connector halves being CADWELDED to the welding cable by the CADWELD PROCESS.
- Insulate both quick connector halves with the hose sections provided.

CADDY®

ARC WELDING ACCESSORY DIV.

ERICO PRODUCTS, Inc.

2070 E. 61st PLACE

CLEVELAND 3, OHIO

NEWS OF THE INDUSTRY

Tempil° Office Moves

Tempil° Corp. announces that on May 1st all facilities, including office and shipping, were consolidated at 132 W. 22nd St., New York, N. Y., where only their plant and laboratory were previously located. This move will provide additional space urgently needed to meet growing requirements.

All communications should be addressed to 132 W. 22nd St. (instead of 11 W. 25th St. as heretofore).

ASTM Meeting June 13th to 18th

An extensive technical program in materials, apparatus and photographic exhibits will be featured at the ASTM 57th annual meeting at Chicago, Ill. The 1954 annual meeting will include 36 technical sessions, hundreds of committee meetings, symposiums on coal sampling, temperature stability of electrical insulating materials, odor, permeability of soils, effect of cyclic heating and stressing on metals at elevated temperatures and methods of testing building constructions.

International Acetylene Assn. Holds Successful Convention

The Fifty-Fourth Annual Convention of the International Acetylene Assn. was held in the Palmer House, Chicago, April 7–9. On the first day, there were meetings of the Acetylene Committee, Motion Pictures of the Industry and several general addresses. Of particular interest to the AMERICAN WELDING SOCIETY were some of the papers given on Wednesday Afternoon and on Thursday. These included papers on "Oxy-acetylene Flame in Steel Production," "Maintenance and Repair in the Steel Mill," "Maintenance of Way," "Car Fabrication, Rebuilding, Repair and Maintenance," "Continuous Welded Rail," "The Use of the Oxy-acetylene Flame in the Petroleum Industry," "Construction and Maintenance in a Chemical Plant," "Repairing Castings from Coast to Coast," and "Special Techniques and Equipment for Oxy-acetylene Welding in Production." There was an interesting Panel Session on "Preventing Welding and Cutting Fires." One of the panel members was S. A. Greenberg, Technical Secretary of the AMERICAN WELDING SOCIETY. The Morehead Medal was awarded to Pierre Philippon, Society L'Air Liquide, Paris, France.

Metal & Thermit Promotions

Metal and Thermit Corp., New York announces the appointment of Frank J. O'Brien, Jr., as general sales manager. Mr. O'Brien, formerly manager of the Heekin Can Co. plant at Springdale, Ark., joined Metal & Thermit in 1951 as manager of its scrap division, and has been a vice-president since 1952.

John B. Tinnon, formerly vice-president and general sales manager, continues as chief executive sales officer of the company with extended activities including general administration and planning and programming for company expansion.

Weld Identification

Tests at California State Polytechnic College on oil transmission pipe-line welds may point the way to a possible change in the current practice of weld identification.

Mechanical engineering students James E. Dearinger, Los Angeles; John W. Hughes, Jr., Oakland, and Gerald H. Schumacher, Placentia, working under the supervision of Richard C. Wiley, welding department head, have been testing pipe welds rejected in the field. The trio, working on an undergraduate thesis, subject the pipes to a fluid pressure as high as 3500 psi before the pipes burst. The pipe, donated by a petroleum company, would carry under normal conditions pressures up to 1100 psi, Wiley points out.

The department head explains that it is common practice for a welder to stamp his identification mark into the pipe on which he works.

"To date, the pipes have given way along the longitudinal lines of the letters or numbers stamped on the pipe," Wiley states. "This leads us to believe that sharp, deep impressions in pipe walls are more liable to cause breaks than defective welds themselves. If additional tests show the same results, it may mean that the industry will have to find another way to place identification marks on pipe, possibly by painting."

Not content with tests already conducted, Dearinger, Hughes and Schumacher are continuing work to determine the effect of factors other than internal pressure. Pipe welds are packed in dry ice and struck with a swinging weight. Results of these tests will demonstrate the effect of temperature variation and sudden blows upon the strength of welded pipe joints.

Low-Temperature Stress Relieving for Pressure Vessels

The Pressure Vessel Research Committee is interested in researches dealing with controlled low-temperature stress relieving of pressure vessels. Lack of information in this field has delayed acceptance of low-temperature stress relieving in the various construction Codes. Preliminary trial tests have shown that in any research program in this field it is important to choose vessels of suitable size and thickness, and to develop careful techniques for stress measurements as, otherwise, the results may be erratic and difficult to interpret.

The Committee would like to receive any unpublished pertinent data and, also, any definite proposals for additional research in this field on some cooperative basis. Suggestions should be addressed to B. E. Rossi, Executive Secretary, Pressure Vessel Research Committee, 29 W. 39th St., New York 18, N. Y.

Welding Clinic, Philadelphia

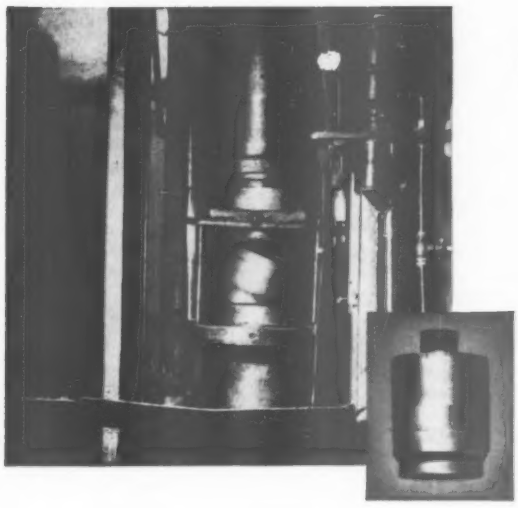
Welding demonstrations using the most up-to-date welding techniques with high nickel alloys highlighted the participation of the International Nickel Co., Inc., in the Whitehead Metal Products Co. Welding Clinic, Philadelphia, Pa., May 25th to 27th.

A feature of the Inco exhibit was the use of Ni-Rod and Ni-Rod "55" in welding cast iron. Other types of welding filler materials were demonstrated for welding nickel, Monel and Inconel. The various metals were welded by inert gas, metal arc and oxy-acetylene processes. Visitors at the show were invited to request demonstrations. Welded specimens were used to further illustrate latest approaches to fabrication problems. Technicians from Inco answered questions on welding, as well as machining, forming, metallurgy and corrosion.

A highlight of the clinic was the grand opening of a new 20,000-sq ft addition to the Whitehead Metal Products warehouse at 1955 Hunting Park Ave., Philadelphia.

W. F. Burchfield, T. N. Armstrong, K. M. Spicer, H. B. Bott, H. C. Waugh and R. M. Wilson, Jr., of Inco's Development and Research Division, J. F. Ryan of the Inco Nickel Alloys Sales Department, and A. E. Smith of the Nickel Sales Department, were in attendance at the Inco booth.

Look How You Save by Hard-Facing



PRODUCTION LIFE INCREASED 1000%

This hard-faced punch mandrel has produced 10,000 pipe couplings and still shows no sign of losing gage. Unprotected tool steel mandrels wore out after punching only 1000 pieces, and case-hardened mandrels punched only 500 pieces before they had to be replaced. A 3/16-in. layer of HAYNES STELLITE hard-facing alloy protects the mandrel from wear and galling.

SAVES $4000 PLUS

Rebuilding this worn extrusion screw with HAYNES STELLITE alloy No. 1 cost $2000—$4000 less than a new screw would cost. And the rebuilt screw will give from 4 to 6 times more service than a new, unfaced screw. The screw is used to extrude rubber from a solid to a semi-liquid state. Wear is the chief problem, and it is effectively resisted by the hard-faced surfaces.

SHEAR 4 TIMES THE TONNAGE

These hard-faced blades shear an average of 200 tons of tough alloy billets. This is more than 4 times the average for special steel blades. Hard-facing with HASTELLOY alloy C protects the blades from wear, and they keep a keener cutting edge longer. When the blades finally do wear, they can be hard-faced again at a fraction of their replacement cost.

FREE—

Write for the 40-page "HAYNES Hard-Facing Manual."

HAYNES *alloys*

Trade-Mark

Hard-facing products made from cobalt-base alloys, nickel-base alloys, and tungsten carbide in the form of rod, wire, and coils.

"Haynes," "Haynes Stellite," "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
UCC
General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

there is a Dockson OUTFIT "complete" at one low price to WELD or CUT

FOR EXAMPLE—The Dockson No. 145 Outfit illustrated above is for light and medium welding and cutting jobs up to and including 5" steel. At one low price you get—

1—No. 4-E-C Hi-Speed Welding Torch ● 1—Ea. Nos. 2, 4, 6, 8 and 10 "E" Style Elbow Tips ● 1—C-4 Hi-Speed Cutting Attachment ● 1—C-2 Cutting Tip ● 1—No. 134-BE Oxygen Regulator, 200 lb. and 3000 lb. gauges ● 1—No. 134-AD Acetylene Regulator, 50 lb. and 500 lb. gauges ● 1—Commercial to P.O.L. Adapter ● 1—12½ ft. length ¼" Siamese Hose ● 4—Hose Connections ● 1—Outfit Wrench ● 1—Round File ● 1—Pr. Series 66-19-6 Welding Goggles. Gas Lighter

YOUR DOCKSON DISTRIBUTOR—is a carefully selected specialist who carries a complete line of Dockson Products in stock to give you fast service and personal attention. We back our distributors 100%.

WRITE FOR YOUR DISTRIBUTOR'S NAME AND OUR COMPLETE CATALOG OF WELDING AND CUTTING EQUIPMENT. BUILT FOR BETTER SERVICE.

Dockson CORPORATION
3239 WABASH • DETROIT 8, MICH.

National Welding Supply Assn.

James N. Alcock, President of the National Welding Supply Assn., has announced the appointment of the following personnel to serve on the NWSA Catalog Committee for the current year: William A. Rice, *Chairman*, Virginia Welding Supply Co., Charleston, W. Va.; Carl W. Berner, Welders Supply, Philadelphia, Pa.; J. L. Kirk, Pocahontas Welding Supply Co., Bluefield, W. Va.; E. C. Caluwaert, O.K.I. Welding Supply Co., Cincinnati, Ohio; and R. S. McCracken, Jr., R. S. McCracken & Sons, Philadelphia, Pa.

Among the Committee's objectives for this year is the study, compilation and establishment of a product-indexing system. Upon completion and adoption, such standard indexing procedures will facilitate more rapid training of Distributor personnel and help to simplify Distributors' sales catalogs.

In addition, the Committee also plans to further publicize NWSA's Official Catalog Standards that were adopted in 1953. Copies of the standards can be obtained by writing Robert C. Fernley, Secretary-Treasurer, National Welding Supply Assn., 1900 Arch St., Philadelphia 3, Pa.

"Weldbrazing" Patent

After ten years of effort, the U. S. Patent Office has granted Karl Spitz of Cleveland, Ohio, Vice-President of the Uniworld Research Corporation of America, U. S. Patent No. 2,664,622 for his "Weldbrazing" method.

The new process was developed by the inventor with the primary objective of avoiding the harmful deterioration of the structure of certain metals, especially steels, in the weld zone as well as in the heat-affected zone, to make possible the welding of those types of metals which are not weldable or are difficult to weld by conventional methods at the present time.

It is claimed that the "Weldbrazing" method is based on the discovery that a steel filler can be nonfusion bonded to ferrous and nonferrous base metals. This is accomplished by creating on the base metal intermediary zones of lower melting and surface-tension reducing elements of high fluidity prior to or with the deposition of the molten steel filler.

The resultant alloy phases have a higher affinity to both base metals as well as to the steel filler which they bond together at a temperature below the melting point of the base metal.

Weldbraze layers have, in general, steel composition (iron content more than 50%); at any rate, however, iron is a dominant constituent in Weldbrazing alloys.

300 Park Ave. Under Construction

An excellent example of the advantages and scope of welding in alteration work is the new 25-story office building now under construction at 300 Park Ave., New York City, for which Emery Roth & Sons are the architects. Uris Bros., the builders, are the first to put an entirely new office building in this area over the New York Central Railroad tracks.

Although the structure is a new one and is replacing an 18-story apartment hotel which is being demolished, a substantial part of this old building, from the first floor down through two levels of New York Central Railroad tracks, is being retained. James Ruderman, Consulting Engineering, who has designed many of the tall office buildings built since the war has in this instance accomplished the unusual feat of supporting the loads of a 25-story office building on a grid of plate girders originally designed to carry an 18-story apartment building. This necessitated the fabrication of members and the use of connections in which welding was not only advantageous, but practically indispensable. Almost every imaginable method of redistributing loads was used on the first and second floors.

The structural detailing under the supervision of Oswald T. Adamec, President of the Precise Drafting Co., involves all phases of the work. The superstructure of the existing building is riveted construction. The first floor area consists of the existing girders with a large number of redistributing girders welded to them. Many of these girders are made up of split 14 WF 426 members, as flanges with webs and cover plates added, all shop welded. Due to extremely heavy loads throughout the first floor area, welding is being used to add stiffeners, cover plates and shear plates to reinforce existing girders. Many loads are so great that double and triple girders parallel to each other were required to carry new columns. Welding is indispensable where existing girders are in pairs and one side of each is inaccessible. The erection and scheduling problems have been eased somewhat due to the flexibility afforded by welding, particularly in the hung ceiling area below the first floor directly over the New York Central Railroad tracks. Much of this work must be done at night to minimize interference with train schedules. Noise is always a factor at night due to the numerous hotels in this area.

The hung ceiling is supported by hundreds of $^7/_8$-in. diam rods, many of which are required to be cut and resupported. Welding provides the only suitable method for this work. The ease in connecting tons of temporary supporting steel by welding will effect a considerable saving in cost and time.

The problems of demolition and simul-

taneous preparation of new work are additional factors that make this building an unusual engineering problem. However, it is the only way practical to replace an outdated building with a new structure in this area.

Renner Expands

Groundbreaking got under way March 15th for the new home of Renner Manufacturing Co. at North 124th St. and West Hampton Ave. in Milwaukee. The new building will measure 102 by 242 ft, plus administration offices, and contain 30,000 ft of floor space. Adjacent lines from the Northwestern Railroad and a main highway will provide convenient shipping facilities. Cost of the new plant is $250,000.

The company has expanded twice in a 10-year period, and now customer demand has forced another increase in facilities, according to George O. Renner, company president. The original firm was organized as a partnership in 1944 to supply heavy industry with fabricated metal parts. In 1946 the company was incorporated, moved to a new plant, and acquired additional equipment. After eight years at this location, another new and larger plant has become necessary.

Symposium on Nondestructive Testing

This informative Symposium was sponsored by ASTM Committee E-7 on Non-Destructive Testing, under the co-chairmanship of J. Smack of Sperry Products, Inc., and D. T. O'Connor, U. S. Dept. of the Navy, and was presented at the Fiftieth Anniversary Meeting of the American Society for Testing Materials in New York, June 1952.

It contains the most advanced nondestructive testing methods and techniques in use throughout the world giving a first-hand view of those used in solving specific nondestructive testing problems in Canada, France, Germany, Holland, Italy and Switzerland.

Although it discusses principally the testing of metal: sheets, rods, castings, forgings, machined assemblies and the like (plastics, too, are mentioned), the Symposium provides excellent data and ideas for nondestructive testing of other materials.

The text is richly illustrated with photographs of equipment, manipulative techniques and oscilloscope patterns when applicable, as well as diagrams and charts. The 6 × 9, 105-page book has a heavy paper cover and is priced at $2.00.

The titles and authors of the eight papers are:

"Comparison Radiographs of Welds," Alexander Gobus and Noah A. Kahn.

"Fluoroscopy and Radiography with Iridium 192," C. Garrett, A. Morrison and G. Rice.

"Weld Radiography: A Tentative Method for Quantitative Evaluation of Defects," Oscar Masi.

"Critical Study of Techniques for the Testing of Materials by Ultrasonic Methods," Paul G. Bastien.

"Comparison of Non-Destructive Tests on a Damaged Sternpost," A. de Sterke and H. den Hartog.

"Progress in the Field of Non-Destructive Testing Through the Use of Ultrasonics," W. C. Hitt.

"The Practical Application of Ultrasonic Non-Destructive Testing," Werner A. Felix.

"Non-Destructive Electronic Sorting of Metals for Physical Properties," Fritz Förster.

Dockson Corporation Appoints National Sales Manager

Dockson Corp., 3839 Wabash Ave., Detroit, Mich., announces the appointment of J. M. (Joe) Gray as National Sales Manager for both their Welding and Head and Eye Equipment Divisions.

Mr. Gray has been associated with Dockson as Regional Sales Manager in the Midwest for the past ten years.

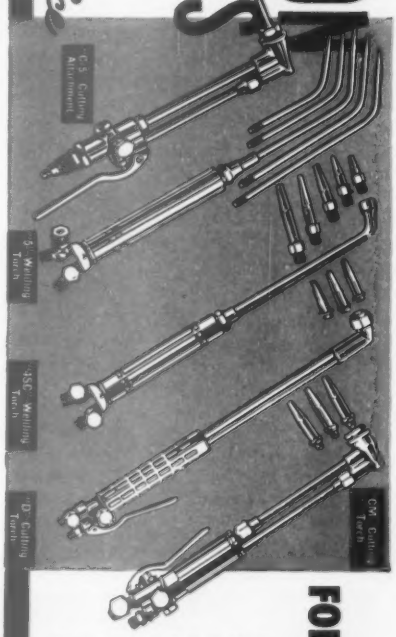
Joe Gray

He is a graduate of Bradley University and was a commissioned officer in the First World War. During the Second World War he served on both the regional and national boards of the Office of Price Administration and the War Production Board.

Mr. Gray was previously a Sales Representative for the B. F. Goodrich Co. for 22 years.

Mr. Gray's headquarters will be in Detroit, where he will also be Sales Manager for Dockson's Detroit retail outlet—The Sterling-Dockson Co.

DOCKSON TORCHES
Built for Better Service



FOR OXY-ACETYLENE WELDING AND CUTTING

There is a Dockson Better-Built Torch for all your jobs. Dockson Torches incorporate a new, longer life, better seal compound developed especially for oxy-acetylene service in both the mixer and union rings. Dockson's two-ring construction means fewer rings to replace, stronger construction, prevention of possible breakthrough.

Your DOCKSON DISTRIBUTOR—a selected specialist, stocks a complete line of Dockson products to give you fast service and personal attention. We back our distributors 100%.

WRITE FOR YOUR DISTRIBUTOR'S NAME AND COMPLETE CATALOG OF WELDING AND CUTTING EQUIPMENT.

Dockson CORPORATION
3839 WABASH • DETROIT 8, MICH.

Southern Oxygen Expands

Southern Oxygen announces a new division to be known as the "Inert Gas Products Division" to handle all products and activities connected with the Inert-Gas Welding Field.

William F. Ruehl

William F. Ruehl is to head the new division as manager. Mr. Ruehl is well known in this field, as he has been performing process engineering both in tungsten and consumable-electrode applications for the past seven years.

A new and modern welding laboratory is being established at Bladensburg. In addition to doing some research work, this laboratory's main function will be to do process service work on Southern Oxygen's customer applications.

Through this division, Southern Oxygen Co. will offer a complete line of apparatus for both metallic inert gas and tungsten inert gas welding.

Air Reduction Safety Film Wins Award

The National Committee on Films for Safety has presented Air Reduction with an Award of Merit in the occupational sound slidefilm class for Airco's new welding safety film, "The Guy Behind Your Back."

Two companies, Air Reduction and an insurance firm, were given awards in this class, of the nation-wide contest.

"The Guy Behind Your Back" is a 20-min, sound slidefilm dealing with safety in the use of oxy-acetylene cutting and welding equipment. Specifically designed for companies to train their own employees, the story is presented in an amusing way with many cartoons and an easy-going narrative. Additional information on this film may be obtained by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

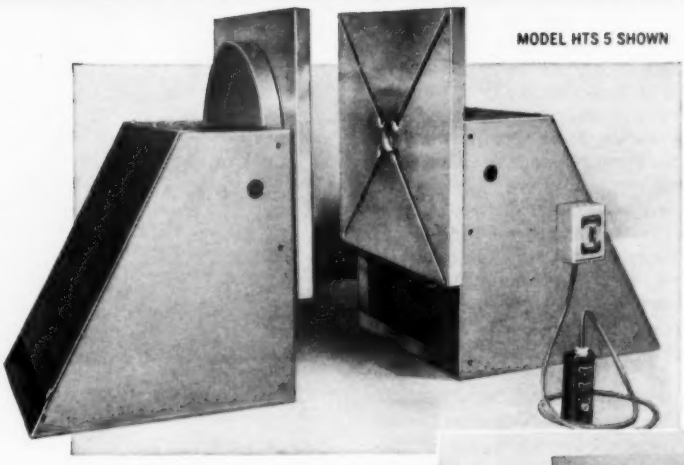
Color TV Uses Stud Welding

Corning Glass Works solved the problem of supporting the large, heavy viewing screen assembly in an accurate location in color TV tubes by the use of end-welded studs which are installed on the flange with a Nelson stud welding gun. Since the picture quality obtainable with these tubes depends upon the relationship of the screen assembly to the base of the funnel (left) where the electron beams are released, accuracy is the problem of first importance in positioning of the studs which cannot be seen after the face plate has been installed.

Aronson HEADSTOCKS — TAILSTOCKS

CLEAN!
SIMPLE!
RUGGED!

Roller Table Backup for *Zero Deflection* • Timken Taper Roller Bearings • Precision Steel Gears • Minimum Backlash • Magnetic Brake • Smooth, Quick Stops • All Working Parts *Enclosed Within* Chassis • Magnetic Reversing Starter *Inside Chassis* • 110 Volt Control Circuit • Positive Drive, No Belts • Mercury Grounded Spindle Headstock *and* Tailstock • All Steel, Welded Construction, No Castings • Only *Two* Grease Fittings to Service *Once a Month*



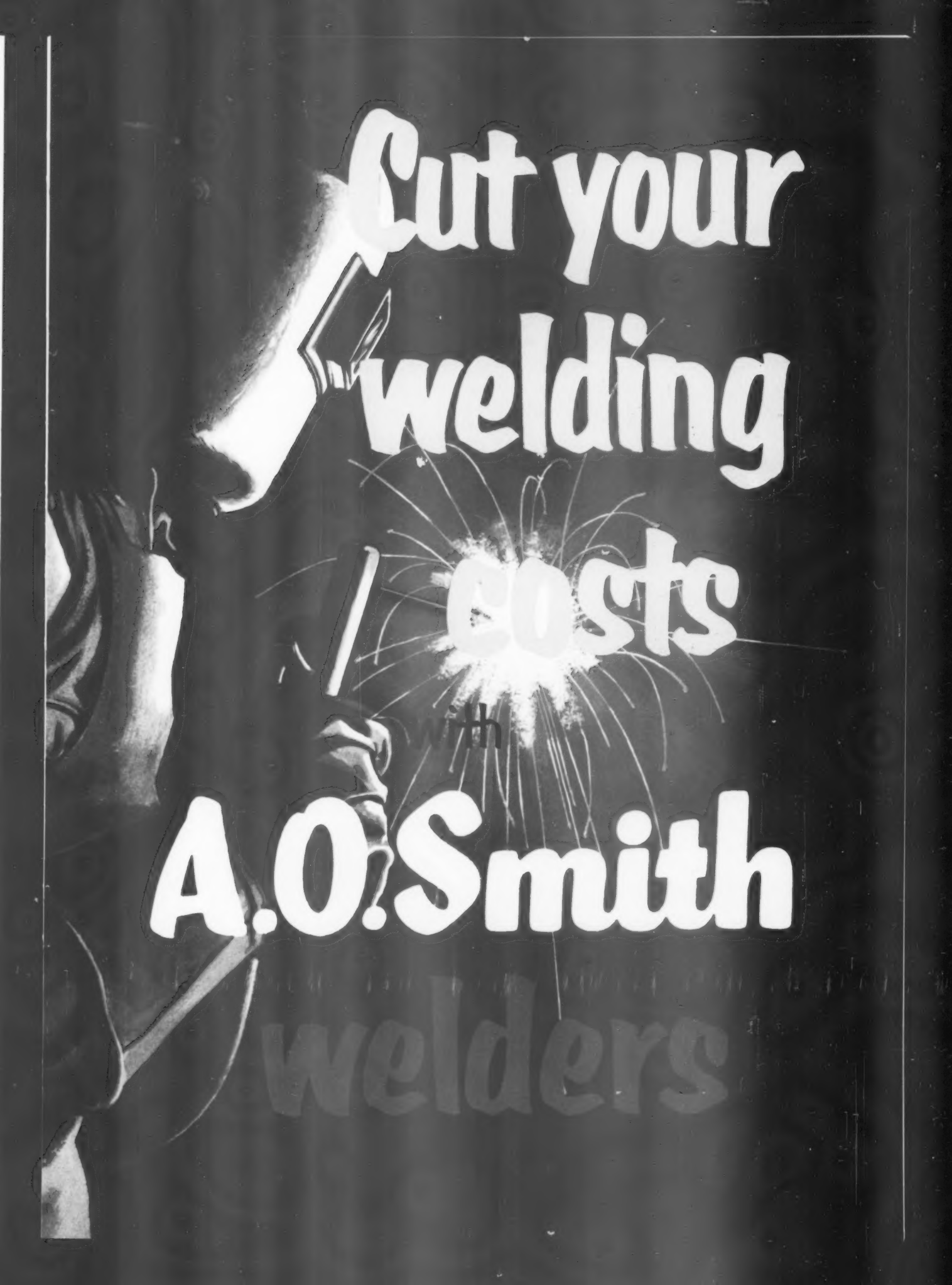
MODEL HTS 5 SHOWN

MODEL HTS 5 — Capacity 5,000 Lbs.
MODEL HTS 12 — Capacity 12,000 Lbs.
MODEL HTS 32 — Capacity 32,000 Lbs.
MODEL HTS 90 — Capacity 90,000 Lbs.
MODEL HTS 160 — Capacity 160,000 Lbs.

Rear view of HS2 Head Stock, cover removed to show clean design and simplicity of drive mechanism.

Aronson MACHINE COMPANY
ARCADE, NEW YORK

WORK WORK


Cut your
welding
costs
with
A.O.Smith
welders

...and get all the

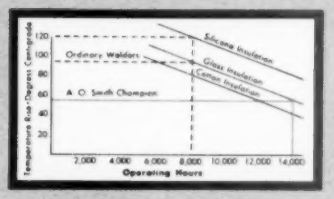
A. C. CHAMPION

heavy-duty welder

Designed and long proved the most dependable power source for continuous operation on the most demanding welding assignments at full rated output.

The CHAMPION has enough copper, plus downdraft ventilation, to assure no more than a 55° C. temperature rise when operating at full rated output. This means almost twice the operating life of any comparable heavy-duty welder!

75 open circuit volts for high-speed welding with a faster and smoother arc! You can "drag the arc" on rapid work and weld low-hydrogen electrodes without "pop-outs." All-weather case makes it as useful outside as in the shop. Available in 300-, 400- and 500-amp models.



The A. C. UTILITY for **farms, garages, machine shops** with dual welding range: 25-90 amps., 35-180 amps

extra benefits

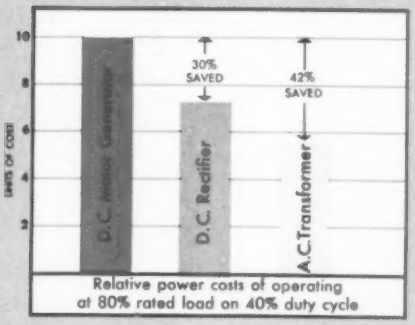
which A. O. Smith design and engineering provide!

D. C.
RECTIFIER
heavy-duty welder

Here is a complete line of N.E.M.A.-rated welding power sources that operate without a single, heavy, rotating part! No motor (other than ventilating fan) and no generator . . . nothing to wear, no commutators to corrode or turn down, no bearings or brushes to replace! Yet they provide a better welding current for all types of work, and operate with unmatched efficiency!

SAVE POWER

Power costs of operating 400-amp. welders are charted below, providing an opportunity to compare motor-generator, rectifier, and AC transformer demands on 40% duty cycle.



Relative power costs of operating at 80% rated load on 40% duty cycle

The savings in power effected by transformer type machines over motor generators result from the improved efficiency under load of the A. C. transformer (85% to 88%) and the D. C. Rectifier (69% to 72%) over the D. C. Motor Generator (45% to 50%), plus the ability of transformer and rectifier to deliver full welding current instantly, when demanded, without requiring large idle-time power to keep rotating parts in motion. The savings are real. In fact, many manufacturers have found that a new transformer will practically pay for itself in a year! Ask your A. O. Smith distributor or representative to show you how, at your next opportunity.

SAVE OTHER COSTS

You save more than power costs when M.G. sets are replaced by A. O. Smith welding machines. Rectifier and transformer welding current inherently has less arc blow, and that means higher quality welds, faster welding speeds and less spatter. It also means greater overall operator efficiency, which assures better weldments, less weld repair and gives the operator greater pride in his work. The result: more money saved and production improved!

Because there are no moving parts, A. O. Smith welders require practically no maintenance. Quiet in operation, they are built to stand up under gruelling production schedules.

Modern successor to the cumbersome, troublesome, lumbering motor-generator set! This welding power source provides smoother arc performance, more dependable amperage at all times, instant striking arcs, and uses power only when welding! It's the only rectifier-type welder designed with high-velocity down-draft ventilation, which draws cool air in over the rectifier stacks before blasting it through the machine. Even when short-circuited at full rated amperage setting, the rectifier stacks remain below critical temperature! Stepless amperage control, effortless and accurate over the full range, assures exactly the desired setting for any job. The three-phase transformer coils are precision wound, of heavy copper, for long service life. Available in 200-, 300- and 400-amp. models.

The **A. C. CHALLENGER** all-purpose welder 200-, 300- and 400-amp. models

The **A. C. AUTO-MAN** for automatic or manual use 650-amp. model, up to 4-unit multiples available

There are A. O. Smith welding power sources for every welding need, built to the highest standards in the industry and of advanced design that makes them more desirable than any other make. Job proved in the shops of the world's largest user of welding as a production tool!

It will pay you to replace M.G. sets with A. O. Smith welders. May we suggest that you write us or contact your local A. O. Smith distributor for full particulars.

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION, Milwaukee 1, Wisconsin

INTERNATIONAL DIVISION: MILWAUKEE 1, WISCONSIN

Highest Quality Welding Electrodes

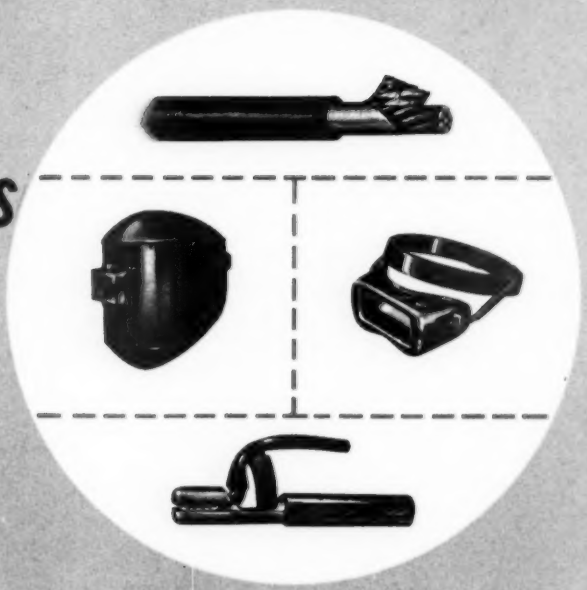
Mild Steel	AWS Class	E6010	E6011	E6012	E6013	E6013	E6013	E6030
	A. O. Smith	SW10	SW14	SW11	SW17	SW15	SW16	SW35

High Tensile	AWS Class	E7010	E7010	E7020	E8013	E9010	E9013	E10013	E10020
	A. O. Smith	SW75	SW80	SW76	SW86	SW95	SW87	SW100	SW101

Low Hydrogen	AWS Class	E6016	E8016	E7016	E8016	E9016	E9016	E10016	E13015	E12016
	A. O. Smith	SW64	SW65	SW84	SW81	SW90	SW89	SW100	SW120	SW103

Stainless	AISI Class	302	308	410	430	308	308	309	309	310	310	310	310	310	316	317	318	347	347
	A. O. Smith	SW131	SW153	SW133	SW134	SW163	SW362	SW166	SW167	SW159	SW339	SW169	SW168	SW360	SW160	SW161	SW158	SW157	SW357

Complete line of welding accessories



All the essentials to put welding to work are available through A. O. Smith. Quality welding cable, connectors, splicers, ground clamps, tongs, and holders; helmets, shields, gloves, and protective clothing; electrode storage ovens, machines and electrodes ... everything required for welding can be had from one responsible source. Take advantage of this for all your welding needs.

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION

Milwaukee 1, Wisconsin

INTERNATIONAL DIVISION: MILWAUKEE 1, WISCONSIN

Made by welders . . . for welders

PERSONNEL

Barnett Joins Armour Research

The former regional sales manager for A. O. Smith Corp., Chicago, has been named supervisor of welding research at Armour Research Foundation of Illinois Institute of Technology, Chicago.

He is Orville T. Barnett, who has a 20-year background in welding and metallurgy. Barnett will be associated with the Foundation's metals research department.

O. T. Barnett

After receiving his bachelor's degree from Illinois Tech in 1933, he was with Carnegie-Illinois Steel Co., Chicago, from 1934 to 1936. From 1936 to 1940, he was an engineer with Black, Sivalls, and Bryson, Inc., Oklahoma City, Okla.

Barnett was district manager for Metal and Thermit Corp. in New York and Pittsburgh, being with that company from 1940 to 1951. He had been with A. O. Smith since 1952.

Barnett has written more than 100 articles for publications in the metallurgy field and is a member of the AMERICAN WELDING SOCIETY and the American Society for Metals.

He, his wife and two children live at 8911 S. Cregier Ave., Chicago.

P. J. Patton as Regional Supervisor

K. W. Horsman, General Manager of Worthington Corp.'s Plainfield, N. J., Works, has announced the appointment of Patrick J. Patton as East Central Regional Supervisor of Worthington's Positioning Equipment Division.

P. J. Patton

Mr. Patton will be headquartered at Pittsburgh and from there will supervise positioner sales activities of Worthington distributors in the Buffalo, Cleveland, Detroit, Pittsburgh and Cincinnati District Office territories.

Widely known in the welding and allied trades, Mr. Patton has spent nearly 20 years studying the techniques and machinery requirements of the metalworking industry.

After his graduation from John Carrol University in Cleveland, Mr. Patton became associated with Arthur McKee & Co. of Cleveland, a leading engineering and contracting firm. He later joined the A. O. Smith Corp. where for several years he served as Eastern District Sales Manager for the Welding Products Division with headquarters in New York.

In 1945, Mr. Patton joined Worthington Corp. in the capacity of Central District Sales Manager for the Positioning Equipment Division with headquarters in Chicago.

Mr. Patton, with his wife and son, resides in the Pittsburgh area.

L. F. Megow Made General Manager

L. F. Megow has joined the Hahn & Clay Machine and Boiler Works of Houston in the capacity of General Manager of their Fabricated Steel Division. Mr. Megow spent 25 years with the A. O. Smith Corp. and was Factory Manager of Smith's Houston works at the time he left that organization.

Hahn and Clay have been in business since 1900 and have grown steadily, keeping ahead of Houston's rapid growth from 50,000 in 1900 to its present estimated population of 690,000. A large percentage of the work of the company is maintenance and repair for most of the large corporations in and around Houston including Shell, Ethyl, Chemical Construction, Champion Paper, Humble, DuPont, etc.

L. F. Megow

Mr. Megow's new address will be Hahn & Clay Machine and Boiler Works, 5100 Clinton Drive, Houston 20, Tex.

Spencer Joins Industry and Welding

Lester F. Spencer has been appointed to the editorial staff of *Industry and Welding Magazine*. Mr. Spencer, who comes from Pratt and Whitney Aircraft, where he has been a process engineer, will be responsible for editorial coverage of the more technical metallurgical aspects associated with the various welding and cutting processes.

He is a registered Professional Engineer in the states of Ohio and Connecticut, and has a Master's degree in Metallurgy from the University of Wisconsin. For 10 years, prior to his connection with Pratt and Whitney, he was chief metallurgist at Landers, Frary & Clark in New Britain, Conn. His experience in the metal-working industry includes many years of research and development as metallurgist for Diebold, Inc., and Republic Steel

L. F. Spencer

Corp. at Canton, Ohio. He is a recognized authority on the fabrication of alloy and stainless steels by resistance, inert-gas-shielded arc, metallic arc welding and brazing.

Mr. Spencer's articles on various aspects of welding have appeared as editorial features in such publications as *Industry & Welding, Tool Engineer, Product Engineering, American Machinist, Iron Age, Materials & Methods, Steel Processing* and many other welding and metal-working magazines. He is a member of the AMERICAN WELDING SOCIETY, the American Society for Metals and the American Institute of Mining and Metallurgical Engineers.

Wilson Elected a Director

The Lincoln Electric Co., Cleveland, has announced the election of Robert Wilson to its Board of Directors. Wilson, a member of Lincoln's sales and engineering staff for the past 17 years, is head of Application Engineering and Director of Training.

Robert Wilson

He started with Lincoln as field engineer shortly following his graduation from Cornell University in 1935. From his field experience he moved into the development laboratory and then into the Application Engineering Department. He assumed responsibility for the department in 1950. The addition of responsibility for training field engineers and dealers in the application of Lincoln's welding equipment was added in 1952.

Mr. Wilson in his application engineering capacity serves industry widely as a consultant on the application of arc welding to all types of metalworking operations. He has made important contributions to many industries through his work in the application of automatic and semiautomatic welding equipment. This type of welding equipment has been developed and introduced during the past 17 years, and Wilson has pioneered its application to the manufacture of products such as railroad cars, tanks, automobiles, pipe, ships and machinery of all types. In recent months he has been involved again in engineering the application of a new development, the use of electrodes containing powdered metal in their coatings.

Pahmeyer Elected Vice-President of Combustion Engineering

Fred O. Pahmeyer and Arthur T. Hunter have been elected vice-presidents of Combustion Engineering, Inc., according to an announcement by Joseph V. Santry, chairman of the Board of Directors.

Mr. Pahmeyer has been general manager of the company's St. Louis manufac turing division since 1927, when the Heine Boiler Co. was acquired by Combustion-Engineering. He originally joined Heine in 1905 following graduation as a mechanical engineer from the University of Illinois. As vice-president he will continue as manager of the St. Louis division. He is a member of the AMERICAN WELDING SOCIETY.

ACME *Automatic* WELDING POSITIONER and FIXTURES

Variations on units shown can be furnished to meet specific requirements.

THIS ACME FIXTURE ARRANGEMENT permits practically constant use of Automatic welding head by reloading opposite fixture during welding operation.

1. Vertical power traverse with up and down inching button.
2. Hand wheel on carriage with locking arrangement for setting automatic welding head in proper relation to work.
3. Positioner arm swings and can be locked in proper position to either fixture.
4. 22" diameter wheel shown on fixture.
5. Fixture equipped with Reeves variable speed for proper feet per minute with reversing control. Fixture with two set speeds can also be furnished.
6. Holding machine can be set in either vertical or horizontal position. Shown in 45° angle.
7. Cross slide adjustment for fine setting so welding head on arm can be placed at either fixture without further adjustment.
8. Heavy copper brushes and holders mounted directly back of fixture for ground.

ACME *Manufacturing Co.*

1400 E. 9 MILE RD., DETROIT 20 Ferndale MICH.

Builders

OBITUARY

G. T. Van Alstyne

G. T. Van Alstyne, 62, Director of Advertising and Publicity, Air Reducton Co., Inc., died Apr. 21, 1954, at his home in Plainfield, N. J.. "Van," as he was affectionately called by his many friends, had been ill since December.

Well known and highly respected in industrial advertising circles, he joined Airco's advertising department in 1919. In 1931, Van was appointed advertising manager for Air Reduction Sales Co., a post he held until Aug. 1, 1952, when he became Director of Advertising and Publicity for the parent company.

Van was a member of various organizations, lending his genial personality and energetic assistance to the activities of the National Industrial Advertising Assn., the International Acetylene Assn. and the AMERICAN WELDING SOCIETY. His worthwhile contributions and pleasant manner will be long remembered by his many associates in advertising and in the welding industry. He served long and faithfully as a member of the Welding Journal Committee and Manufacturers Committee of the SOCIETY.

Hermann Lemp, Noted Engineer, Passes Away at 91

Ridgewood (N. J.) News, Sunday, April 4, 1954

Hermann Lemp, internationally known electrical engineer, died on March 31st after a lingering illness at the home of his son-in-law and daughter, Mr. and Mrs. John B. Woodward, of 415 E. Saddle River Rd., Ridgewood, with whom he and his wife had been living ever since they left their home in Glen Rock five years ago. His age was 91.

He was born in Switzerland, Aug. 3, 1862, and came to this country as a young man, working originally with Thomas Edison in the old Menlo Park Laboratory, where he got a job in 1881. Before coming over he had been working in a factory in Switzerland which made precision electrical instruments, and studying on the side in the University when the first electrical exhibition was held in Paris. It was at this exhibition that his interest in the science to which he was to devote the rest of his life was aroused and, after seeing some of the Edison marvels shown there, he was determined to get to America and contact the great inventor.

After working two years in Menlo Park young Lemp was made chief engineer of the Schuyler Electric Co. at Hartford, Conn., in 1883 continuing there until 1887. Subsequent positions he held were: As chief engineer with the Thomas-Houston Electric Co. 1887–89; as chief engineer with the Thomas Welding Co. of Lynn, Mass., 1889–95; as electrical engineer with the General Electric, Lynn, 1895–1911; as works engineer with the General Electric of Erie, Pa., 1912–25; as chief engineer with Erie Steam Shovel Co., 1925–26, and as consulting engineer of Locomotive Department, Ingersoll-Rand Co., 1926–33.

When the Ingersoll-Rand Co. decided to build Diesel-electric locomotives—a new venture—Mr. Lemp who had been sent abroad to get information about this type of engine, and who advocated its construction, was made chief engineer for the project at the company's Erie plant. The engines proved eminently successful. He was awarded the Henderson medal of the Franklin Institute for his pioneer work in that connection, and was also made a fellow of the American Institute of Electrical Engineers.

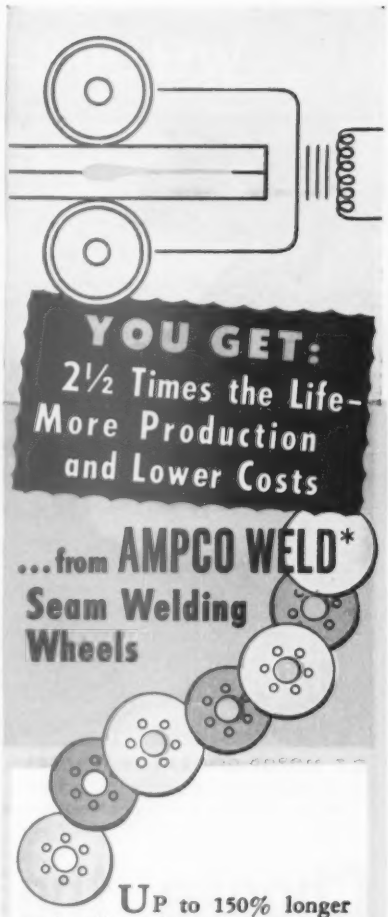
Surviving are his wife Alice M. Lemp, a daughter Boudy (Mrs. John B.) Woodward, of Ridgewood; a son Harry Lemp of Bradenton, Fla; five grandchildren, and several great-grandchildren.

A private memorial service was held at his home Saturday, April 3rd.

Employment Service Bulletin

Services Available

A-651. Welding Engineer. Graduate with MS degree. Age 31. Married with children. Veteran. Over five years' experience, one year in resistance welding production and more than four years in welding research and development. Prefers an industrial position involving the application of welding methods to production, particularly resistance welding. Position must have good opportunities for advancement. Will relocate.



UP to 150% longer service life — that's the record reported by users of Ampco Weld tube and seam welding wheels. And here's why: Ampco Weld wheels have unusual hardness and toughness at elevated temperatures — exceptional resistance to wear — extra durability. And they also have uniformly high electrical conductivity. All this adds up to longer runs, fewer shutdowns, increased production, lower costs.

You can order Ampco Weld wheels as rough forgings, finished blanks, or fully machined, as you prefer.

Ampco Weld wheels are part of an extensive line of Ampco resistance-welding products. All meet or exceed RWMA specifications. And Ampco offers you free, expert engineering service for specialized applications, if you want it. Order Ampco Weld wheels today — watch production step up, costs step down.

AMPCO Ampco Metal, Inc.
MILWAUKEE 46, WISCONSIN
West Coast Plant: Burbank, California

*Reg. U. S. Pat. Off. AW-7

WELDING ARCS NEWS

G-E MOTOR-GENERATOR WELDERS are simple to operate. A single-dial, dual-control current indicator makes it easy for you to set and check current —to get the best in welding performance.

G-E AC TRANSFORMER WELDERS feature instant arc striking through automatic hot-start, and capacitor-stabilized arc.

G-E RECTIFIER WELDERS offer you quiet, low-cost operation, plus the advantages of motor-generator welders.

Choose the best welder for your job from the full line of G-E equipment

Only G.E. offers all three—a-c, m-g, and rectifier

Any welder may "do," but only one type is *best* suited to your particular job. Only one will provide top performance at the lowest possible cost.

You will find this particular welder in the complete General Electric line—the only line which includes all three: a-c, m-g, and rectifier. Choose the right welder for your job; choose from the complete line.

AC SET PROVIDES EASY-TO-HANDLE ARC

For welding heavy sections at high travel speeds—without troublesome arc blow—select a G-E a-c welder. You can use bigger electrodes, higher current —make fewer passes. G-E a-c welders give you easy starting and a stable arc for dependable operation.

MG SET OFFERS UNIQUE INTERACTOR

For the wide variety of industrial applications where d-c welding works best, select a G-E motor-generator set. This set offers the unique interactor, which smooths out voltage fluctuations—producing a steady arc, and stronger welds.

Single-dial, dual-control makes it easy for you to choose the proper current and voltage setting to give top welding performance.

RECTIFIER SET HAS MANY AC, DC BENEFITS

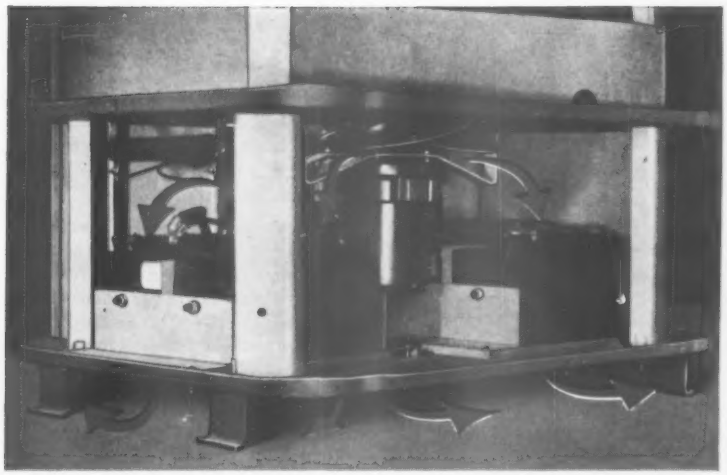
Quiet, low-cost operation, and low maintenance expense—these are just a few of the benefits you get with G.E.'s new rectifier welder. Its soft arc can be made penetrating at the flick of a switch.

Only G.E. offers full-time, arc-force control, to give you all the advantages of d-c welding. For more data on the exclusive features of this powerful rectifier welder, see the next page, and. . .

CONTACT YOUR G-E DISTRIBUTOR TODAY

Learn more about how you benefit from choosing from the complete G-E line—ask your distributor for free bulletins and information. His name is listed on the opposite page, and on the yellow pages of your phone book, under "Welding Equipment—General Electric." General Electric Co., Schenectady 5, N. Y.

(710-17)



REVERSE-DRAFT FAN becomes a dust blower at the flick of a switch. Rectifier stacks may be periodically cleaned in this way to prolong the life of the equipment.

New G-E rectifier welder offers unique money-saving features

General Electric's powerful new 400-amp rectifier welder provides you with two practical features you will not find in any other rectifier set: full-time arc-force control, and a reverse-draft fan.

FULL-TIME ARC-FORCE CONTROL

With G-E full-time arc-force control (optional equipment) you can hold a short arc on those extra-tough welding jobs with little chance for pop-outs or freezing in.

POWERFUL REVERSE-DRAFT FAN

A powerful ventilating fan in G-E rectifier welders can be reversed easily to blow dirt off rectifier stacks. This cleaning action minimizes a major cause of rectifier failures.

FOR MORE INFORMATION

See your G-E Welding Distributor for full details. His name is listed on this page and in the yellow pages of the phone book under "Welding Equipment—General Electric."

MEMO:

Ask about the three star-performers featured at the AWS Welding Show:

G-E RECTIFIER WELDER—the rectifier with the new features—aimed at long service with a minimum of interruptions in production.

G-E FILLERARC—for consumable-electrode, gas-shielded welding. The gun feeds wire by PULLING—allowing thinner wire for welding thinner sections.

G-E STRIKEASY 1—the new electrode with a powdered-iron coating. Boosts deposition rates so high you can save up to 35% in costs.

G-E WELDING DISTRIBUTORS

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Company

Florida: Hollywood—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis — Sutton-Garten; South Bend — Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Wichita—Standard Products

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Oklahoma City—Hooper Supply

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—H. & W. Welding Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

GENERAL ELECTRIC

NEW LITERATURE

Metals and How to Weld Them

Written by T. B. Jefferson, Editor, *The Welding Engineer*, and Gorham Woods, Metallurgist, *Metals and How to Weld Them* is a new book for the welding operator, supervisor, instructor, engineer, designer and manager. It explains in clear, logical, readily understood steps the structure and properties of metals and how to weld them; covers the fundamentals of metallurgy and their significance for welding metals; gives procedures for welding mild, medium and high-carbon steel, alloys, cast iron, hardfacing, stainless and high chromium steels, austenitic manganese steels, tool and die steels. It tells how to make good welds; gives information on trouble shooting, welding terms and other useful data. It contains 322 pages, over 170 drawings, photographs and tables; stiff-board, cloth-covered binding, gold embossed. Price $2.00 in U.S.A., $2.50 elsewhere. Publisher, The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

Couplings

A catalog describing convoluted couplings, a new addition to Solar Aircraft Co.'s line of industrial expansion joints, has been published by the company's Bellows Division.

Designed and engineered to meet industrial needs for low pressure and vacuum service joints, the new Sola-Flex couplings embody novel convolution contour design that results in an unusually low spring rate, with consequent high-life cyclage. The convoluted couplings are low in cost and are available in stock sizes from 1/2- through 72-in. pipe sizes, and supplement Solar's line of high-pressure expansion joints.

The new Solar publication includes complete engineering data, with spring rates, deflection forces and dimensions. The 16-page catalog includes ten pages of tables giving complete data on each size and type of coupling, along with dimensional diagrams and a group of formulas for calculating various movements of couplings.

The new catalog, No. 55, supplements Solar's earlier catalog No. 51 which covered industrial expansion joints and bellows. Copies of Catalog No. 55, "Convoluted Couplings," can be obtained from the Bellows Division, Solar Aircraft Co., 2200 Pacific Highway, San Diego 12, Calif.

Gas Regulators

Air Reduction's complete line of gas regulators is fully described in the new 36-page catalog now being offered. Cylinder, manifold and pipe-line regulators are illustrated with complete descriptions covering specifications and operating data.

Each regulator has a chart showing types of gages used with it, inlet and outlet connections, maximum flow in cubic feet per hour and maximum working pressure in pounds per square inch.

For easy reference, the catalog is cross indexed so that a particular regulator may be located by its uses and by its gas service.

Also included are flow and pressure charts indicating at what point the regulators can be used to perform a particular job.

For complete information, request a copy of this catalog by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Ampco Welding News

The first quarter of the 1954 *Ampco Welding News* which is issued by the Weldrod Department of Ampco Metal, Inc., presents several interesting and informative articles regarding specific products that incorporate Ampco's quality material.

Feature articles include a story of Scoopmobiles and how Ampco-Trode 10 improved its production and functioning operations. Other articles present a very effective and economical method of minimizing sliding friction; consequently cutting down wear. Specific past proved applications are cited in these articles and are most helpful in solving similar application problems.

Announcements of new Ampco products which include the Ampco-Weld Recap Tips, and Wire Brushes for Safety in addition to other short news items are also included in the issue.

Free copies of this publication may be obtained by writing to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Eutectic Releases Maintenance Manual

A new, fully illustrated, 16-page manual on the maintenance and repair of sugar mill equipment, agricultural implements, rolling stock and machinery has been issued by Eutectic Welding Alloys Corp.

Although this manual is specifically slanted to the requirements of the sugar industry it will be of inestimable value to all who are faced with the problem of plant maintenance and the repair and protection of machinery and agricultural implements.

The manual is in case history form. Each represents a problem which was solved with soldering, brazing or welding materials and procedures. Every phase of the operation is illustrated by step-by-step pictures. The alloy used, the recommended method and, in many cases, the savings effected are described fully.

Write Eutectic Welding Alloys Corp., 40–40 172nd St., Flushing 58, N. Y., for your free copy.

Portable X-Ray Unit

A new 4-page folder titled "Norelco MG 160" that describes a new portable self-contained industrial X-ray radiographic unit is available gratis from the Research & Control Instruments Division, North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

Illustrated with a number of photos, the new literature explains the X-ray head, the control and other features of the MG 160 unit which is easily carried in the trunk of an automobile.

Application data are given which are useful in examinations of stressed components, welds, frames, castings, steel structures, hidden assemblies, ceramics and plastics.

Blow-Off Line Univalves

Catalog 12-D1 just published by Edward Valves, Inc., subsidiary of Rockwell Manufacturing Co., features a redesigned line of blow-off valves with flanged or welding ends and bolted bonnets for 300, 400–600, 900–1500 lb sp classes plus the addition of welded bonnet blow-off valves with welding ends for 1500- and 2500-lb sp classes.

The new line retains the many Edward features such as interchangeability of parts, line contact backseats, condensate cooling chamber to protect the packing, both valves in a set capable of tight shut-off, self-centering disk with swivel construction that allows stem to turn on the disk instead of the disk turning on the seat. Some of the new features include improved streamlining of interior body contours, swing gland bolts for easier repacking and stellited seating surfaces for lower pressure classes.

NOW YOURS **Free!**

ASK YOUR SYLVANIA DISTRIBUTOR FOR THIS GREATEST OF

Time-Saving Welding Charts

No more guess work about inert gas welding! Here's a helpful, new chart based on research by Rensselaer Polytechnical Institute. Gives you valuable facts and short cuts . . . helps you save time, material, and money.

EASY-TO-READ TIPS

This folder lists your most troublesome welding problems and gives a solution side by side. *Tells what to do about difficult starting, brittle electrode tips, contamination, excess heat . . . and many other tricky problems.*

So pick up your phone and ask your Sylvania Welding Distributor to drop a couple of these charts in the mail for you, FREE. Also check your supply of Sylvania packaged electrodes... Thoriated Tungsten, Puretung, and Zirtung... the rods tested for quality and uniformity from ore to finished products. For any further information write to Dept. 4T-4606, Sylvania TODAY!

Speeds work, Avoids trouble, Saves dollars!

SYLVANIA

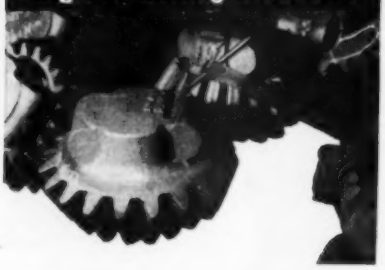
In Canada: Sylvania Electric (Canada) Ltd., University Tower Building, St. Catherine Street, Montreal, P. Q.

Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.

LIGHTING · RADIO · ELECTRONICS · TELEVISION

ARCAIR TORCH

"saves labor and operating expense" in gouging out casting errors...



"Operators prefer the Arcair Torch because it is lighter, faster and not as 'hot' to operate," says the foreman of the cleaning and welding shop of a midwestern foundry.

This foundry produces nominal alloy gear blanks for use in heavy duty trucks. Such casting operations often necessitate a certain amount of gouging to remove cracks, errors and other defects from the castings.

On production-line jobs like this, simplicity, ease of operation, economical performance and smooth, even cuts are essential. The Arcair Torch, using only carbon arc and compressed air, fits these requirements better than other gouging, cutting or chipping methods.

Gouging out a nominal alloy casting with the Arcair Torch leaves a clean, smooth groove, ready for welding.

For almost two years this foundry shop has been using six Arcair Torches. Says the foreman, ". . . now the men will not operate without them."

THE NEW MODEL "J-5" ARCAIR TORCH is a rugged, heavy duty torch specially developed for foundries and other production-line operations . . . removing excess metal, gouging out cracks and removing defective welds.

Low in original cost and low in maintenance cost, the "J-5" is designed for simplified operation on continuous heavy duty applications. The "J-5" features a fixed electrode angle and automatic air control . . . the air valve is on as long as the electrode remains in the torch. The "J-5" can be operated in any direction or position without adjusting electrode angle or air controls, or changing grip on the handle.

Write for free bulletin with facts and photographs of time and money-saving applications of the Arcair Torch.

ARCAIR COMPANY
EASTERN DIVISION:
P.O. Box 337,
Lancaster, Ohio
WESTERN DIVISION:
P.O. Box 4227,
Bremerton, Wash.

Arcair TORCH

Cuts all metals—using only electric arc and compressed air

Copies may be obtained by calling or writing your nearest Edward representative or writing directly to Edward Valves, Inc., 1211 W. 145th St., East Chicago. Ind.

Standards in a Changing World

Publication of *Standards in a Changing World*, the proceedings of the Fourth National Standardization Conference held in New York, Oct. 19–21, 1953, is announced by the American Standards Assn.

The 80-page booklet contains the papers presented at the Standardization Conference and the addresses made at the 35th Annual Meeting and Awards Luncheon of the American Standards Assn. (ASA).

Among the papers are 35th anniversary commemorative addresses by officials of the five engineering societies which founded ASA in 1918—American Institute of Electrical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials and American Institute of Mining and Metallurgical Engineers.

Other sections of the booklet contain panel sessions on purchasing, quality control and factors involved in organizing company standards; a symposium on industrial noise; and a report by the National Bureau of Standards on design and production of electronics.

The address made by Senator Ralph E. Flanders (Rep., Vermont) on receiving the Howard Coonley Medal for work in standards is also included.

The booklet is sold by the American Standards Assn., 70 E. 45th St., New York 17, for $3.00. Review copies are available to editors on request.

Welding Elbows

ASME Paper No. 53-A-70, "In-Plane Bending Properties of Welding Elbows," was recently presented at the annual meeting of The American Society of Mechanical Engineers at a joint session of its Power, Applied Mechanics, Heat Transfer and Petroleum Divisions and of its Research Committees on Effect of Temperature on Properties of Metals and High-Temperature Steam Generation.

The paper presents results of strain gage investigations conducted on relatively heavy wall WeldELLS having a ratio of bend radius to nominal pipe size of $1^1/_2$:1. Also, several WeldELLS having a ratio of bend radius to nominal pipe size of 1:1 were tested. A comparison is made of the results against theory. Design factors for WeldELLS are established and tabulated.

The purpose of the paper is to provide design engineers with accurate, experimentally derived flexibility and stress intensification factors applicable to welding elbows commonly used in high-pressure steam, oil refinery and gas compressor station piping systems. It is aimed at filling a now existing gap in the practical design information available for a class of fitting having wide industrial use.

Reprints of this paper are available (as Bulletin 534), from Taylor Forge & Pipe Works, Chicago 90, Ill.

Safety Booklet

"Safety" is a new 32-page booklet now being offered by Air Reduction. It is specifically designed for welding and cutting operators handling oxy-acetylene and arc-welding equipment.

Based on the principle that "safety is no accident," the booklet details safety cautions and rules for personal safety, the handling and maintenance of cylinders, torches, regulators and hoses. It discusses safe practices in setting up, adjusting, using and shutting down of the equipment. The story is presented in a clear, concise way with sketches illustrating safe practices as well as some of the malpractices in the welding and cutting field.

Copies of this booket may be obtained by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Hard-Facing Alloys

Three new cobalt-chromium-tungsten hard-facing alloys in welding rod form are announced by Crobalt, Inc. Known as Crobalite alloys, these materials are applied to steel and cast-iron parts to provide high hardness and high resistance to abrasion, corrosion, oxidation and impact. They retain these properties at red heat, can be heated to 1600° F with no permanent loss of hardness, and are not affected by repeated heating and cooling.

These alloys are applied by oxy-acetylene torch or inert arc welding, either manually or by semiautomatic machine, using standard hard-facing procedures. They flow on readily in a uniform, slag-free layer, and bond firmly with minimum interalloying. When applied, they consist of a dense, hard layer of complex wear-resistant carbides evenly distributed in a cobalt matrix, essentially identical to Crobalt cast-alloy cutting tools.

Full details and typical applications are given in Crobalite Bulletin 102, available on request from Crobalt, Inc., 2800 S. State St., Ann Arbor, Mich.

Stud Manual

New instructions on how to parallel two units for welding large diameter studs are among the important changes incorporated in a revised *Nelwelder Power Unit Manual* just issued by the Nelson Stud Welding

Division, Gregory Industries, Inc., Lorain, Ohio. This unit is designed specifically for the operation of stud-welding equipment and is not usable for conventional arc welding.

The revised manual contains new paralleling diagrams. It also includes information on performance possible with the Nelwelder power unit, models available, power and fuse requirements, and general instructions on installation, operation, and maintenance. The parts list contains drawings, code numbers, names and descriptions of all parts.

An additional feature of the manual is a complete directory of more than 190 field service shops and Nelson offices, warehouses and distributors through whom parts and service for Nelwelder power units are available.

Alloy Steel Castings

A designation chart for cast stainless steels has just been prepared by Empire Steel Castings, Inc., Reading, Pa., makers of stainless, carbon and low-alloy steel castings.

The new chart designates specifications, analysis, physical properties and uses of a number of corrosion-resistant and heat-resistant stainless steels. It correlates the AISI type number and ASTM and SAE designations with the Empire Steel and ACI designations, so that users can readily identify the properties of their castings. In addition, principal alloying elements are given, and helpful remarks regarding behavior of each steel in use are included.

For further information or a copy of the chart write to Empire Steel Castings, Inc. Box 139, Reading, Pa., for Bulletin 454-S.,

Elements of Structural Engineering

This important textbook by Ernest C. Harris, Chairman of Dept. of Civil Engineering and Engineering Mechanics, Fenn College, presents structural engineering from the point of view of the noncivil engineering student. The application of principles is largely in terms of examples and problems encountered by mechanical, electrical and other noncivil engineers.

The presentation of structural theory is brought out by applying it to cranes and conveyor supports rather than the more conventional example of a railway or highway bridge; engineering principles inherent in the complete original design of buildings are exemplified by analyzing the effect of new electrical or mechanical equipment on the safety of existing structures.

Copies of this book may be obtained by writing to The Ronald Press Co., 15 E. 26th St., New York 10, N. Y. Price $7.00.

Page Welding Wire

Now—a new line-up of PAGE welding wire in coils, reels, packages

• Here are some of the ways PAGE welding wires are packaged to protect them during shipment and to make it easy for you to handle and stock them. Two new packages are Leverpaks and pallet-mounted coils.

LEVERPAKS • Here's one of the best containers for coils up to 16″ ID. It's light-weight, but durable. It is sealed air-tight and is packed with moisture-absorbing substance to reduce corrosion. Release safety catch, pull lever, and the whole top comes off. It's just as quickly resealed. Leverpaks can be rolled easily. They stack perfectly and take a minimum of floor space. They cost you nothing extra and have many re-uses.

PALLET-MOUNTED COILS • If you have a fork-lift truck, you'll like PAGE'S new pallet-mounting of 22″ ID coils. Steel strapping and paper wrapping protect coils and hold them securely. You can run them in and out of freight cars and trucks, and spot them in your plant.

AUTOMATIC WELDING WIRES • **Inert Gas**—Six PAGE-ALLEGHENY stainless grades in .035″, .045″, and .0625″ diameters. Precision thread-wound on 25-lb. non-returnable reels to fit popular arc welding machines. **Submerged Arc**—PAGE Stainless in wire diameters from 1/32″ to 5/16″, plain or copper coated. In layer-wound coils or 22″ or 24″ mill coils.

GAS WELDING RODS • In a variety of analyses: stainless, Armco, medium and high carbon, and manganese or naval bronze.

Warehouse stocks in Chicago, Denver, Houston, Los Angeles, San Francisco

Write our Monessen, Pa., office for literature and prices

ACCO

Page Steel and Wire Division

AMERICAN CHAIN & CABLE

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Portland, Ore., San Francisco, Bridgeport, Conn.

GAS Automatic Arc

NEW PRODUCTS

Low-Cost Manipulator

A new, low-cost method for converting a portable semiautomatic flux-type welding head into a highly productive tool is provided by the new Welding Head Manipulator recently introduced by Pandjiris Weldment Co. Although technically known as the Semi-Automatic Manipulator, it will be called SAM for short.

Piloted by SAM, the head produces welds which are smoother and more even than is possible with manual operation.

SAM's applications are many. It makes longitudinal and circumferential welds on tanks . . . welds on items too large and bulky for positioners to handle . . . on weldments positioned by welding work positioners.

SAM is available with either hand or power lift for raising the weld tip to an arc height of 7 ft 6 in. above the floor line. Horizontal arc travel is 8 ft. Fully reversible, infinitely variable speed boom makes possible welding speeds from 0 to 120 ipm, in either direction.

Adjustable bracket for cone mounting permits fillet welding and there's a micrometer screw adjustment for vertical positioning of the welding tip.

The entire unit is mounted on antifriction roller-bearing casters for easy movement from job to job. Also available on a fixed base.

Further information on SAM may be obtained by writing Pandjiris Weldment Co., 5152 Northrup, St. Louis, 10, Mo.

Torch Overlay

A new, improved, low melting overlay for frictional wear resistance on ferrous and nonferrous metals, trade named EutecRod 186, has been developed by Eutectic Welding Alloys Corp.

It is recommended for overlaying surfaces subject to frictional wear whenever a copper base alloy is required. It can be used for building up or overlaying steel, cast iron, copper and alloys of copper and nickel. It is excellent for building up bearings, overlaying shafts, valve seats, etc. The low heat of application, 1400–1600° F (which is considerably lower than that required by conventional bronze welding rods), minimizes the danger of distortion and warpage and the alloy gives an excellent color match when applied to manganese-bronze castings.

Further particulars may be had by writing to Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y.

Improved Ground Clamps

Redesigned to fit the hand, the arc-welding ground clamps shown in the accompanying photo work easier and faster, open wider to grip the workpiece.

New angle of cable socket reduces strain on the cable. Provision is made for additional fastening of the cable in back of the socket to further reduce cable damage.

The large, flat contact area of the copper alloy upper tong has been retained to provide sure conductivity between clamp and work.

Clamps are made in three models to fit cable sizes 4 through 4/0.

Jackson Products, Inc., 31739 Mound Rd., Warren, Mich.

Four-Purpose Electrode

A new electrode the "Cham-Cut," specially designed for electric-arc cutting, chamfering, gouging and piercing, has been placed on the market by Pacific Welding Alloys.

Flux-coated with a special alloy, the "Cham-Cut" has a very fast cutting rate and is highly effective for work on all types of steels including cast iron, and stainless, as well as copper and nickel alloys. Extremely economical, the new "Cham-Cut" electrode requires no special equipment as is the case with other cutting methods.

The new rod can be used with a-c, d-c reverse or straight polarity current, and is currently available in 1/8, 5/32, 3/16 and 1/4 in. sizes. "Cham-Cut" is packaged in 10-lb metal containers for protecting against scuffing and rusting.

Samples of the new "Cham-Cut" electrode plus full technical information are available on request from Pacific Welding Alloys Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

Correcting Defects

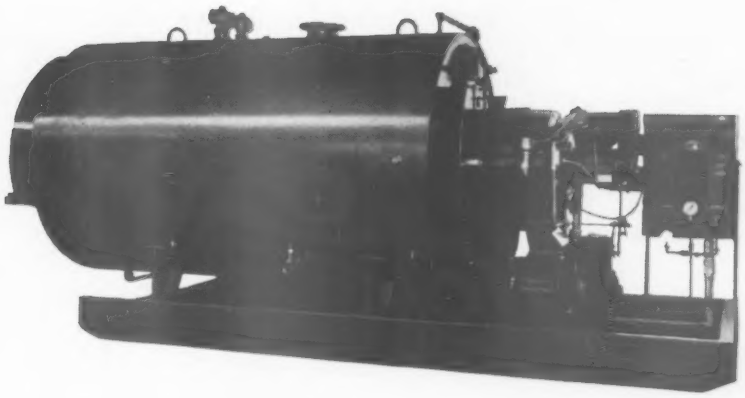
A simple, yet ingenious, method of correcting defects and removing excess metal from large steel castings, known as the Kwik-Arc Jet Torch Process, has resulted in better quality work and reduced these time-consuming cleaning operations by as much as 75% for the ACCO Casting Division, American Chain & Cable Co., Reading, Pa.

Now in its first year as standard foundry procedure, the 6000° F torch has eliminated a former backlog of castings awaiting the chipping and grinding operation, and is much easier to handle than a pneumatic chipping gun.

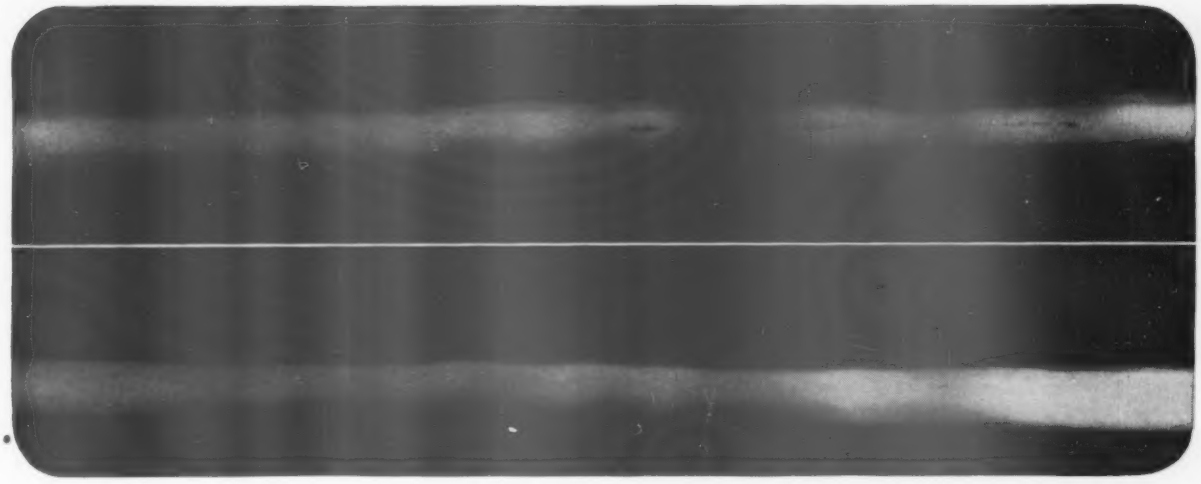
The jet torch consists of a 1/2-in. diam carbon electrode, secured in a holder, with a small air jet beneath it. When ignited, the electrode generates an electric arc of 6000° F which melts, shrinks, cracks fused-in sand, fins, brackets, nails, etc., like water. The accompanying jet of air blows the molten metal and slag away, leaving a casting of generally uniform contour. The jetted area cools in a few minutes and is then rebuilt with sound weld metal before the casting reaches the chipping and grinding operation.

In addition to speeding up the cleaning operation, this process removes much less "parent metal" than is possible with a chipping gun, and keeps subsequent welding and grinding to a minimum. It does not, however, cover up defects which might show up later.

The ACCO Casting Division, a leading producer of medium-sized castings for railroad, electrical and farm equipment use, reports the new process to be relatively inexpensive. The main outlay was for the erection of metal welding booths to house the operation and to protect other workers in the area from the intense light. The jet torch operator wears a welder's helmet and the usual protective clothing.



WEIGHT DOWN 15%—COSTS DOWN 10%



...BECAUSE *RADIOGRAPHY* PROVES IT SOUND

WELDING does great things for pressure vessels. Take this steam boiler for example. It saves 15% in customary weight—saves 10% to 20% in costs, depending upon design pressure. What's more, the job is smooth, clean and neat.

Welding can be used because Radiography proves every seam sound. It would be quick to reveal any serious lack of fusion or gas porosities.

This is just an example of how Radiography frees the designer's hand and widens the opportunities for welders.

It can increase your business. Want to know how? Get in touch with your x-ray dealer and talk it over.

EASTMAN KODAK COMPANY
X-ray Division, Rochester 4, N. Y.

Radiography...

another important example of Photography at Work

Kodak

Bulletin 17

The Welding Research Council and the Ship Structure Committee have joined forces in publishing and making available to industry an interesting comprehensive report entitled:

A Critical Survey of Brittle Failure in Carbon-Plate Steel Structures Other Than Ships

by M. E. Shank

This report covers both riveted and welded failures and should form part of the library of anyone concerned in any way with the problem of brittle fractures.

Now on Sale

Price $2.00

AMERICAN WELDING SOCIETY

33 W. 39th St.,

New York 18, N. Y.

WANTED

for Murder...

CANCER is the cruelest enemy of all. No other disease brings so much suffering to Americans of all ages.

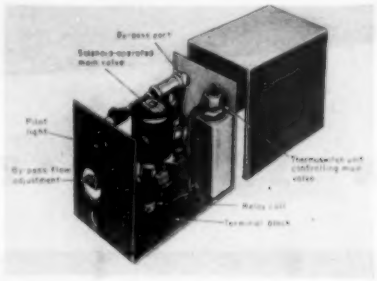
YET—though 23 million living Americans will die of cancer, at present rates—there is reason for hope. Thousands are being cured, who once would have been hopeless cases. Thousands more can have their suffering eased, their lives prolonged. And every day, we come closer to the final goal of cancer research: a sure and certain *cure* for all cancer.

THESE THINGS have all been helped by *your* donations to the American Cancer Society. *This* year, please be especially generous!

Cancer
MAN'S CRUELEST ENEMY
Strike back—Give
AMERICAN CANCER SOCIETY

Automatic Valve for Cooling Water

The operator of water-cooled machines—such as induction heating equipment, resistance welders, hydraulic systems, air compressors, etc.—has two important responsibilities: first, remembering to turn the water on when the equipment goes into use; second, shutting off water flow at the end of the operating cycle, but *not*



before the machine has cooled to a safe temperature. To be on the safe side, many operators allow the cooling water to flow continuously, even though the machine may be used intermittently. Large amounts of water can be wasted this way. A more foolproof and economical procedure is to install a simple, automatic flow valve on the water lines.

An automatic valve can reduce water consumption substantially, while at the same time assure positive cooling. For example, a large midwest manufacturer of farm implements installed such a valve in a cooling water line to a 300-kva projection welder. Metered water consumption before installation averaged 3802 gal per day; after installation, it dropped to 641 gal—a saving of 3141 gal (82%) per day on a single welder.

The Water Mizer is manufactured by Van Vooren Products, East Moline, Illinois. Fenwal, Inc., Ashland, Mass. produces the water thermostat which is an integral part of this equipment.

Spray Unit Applies Hard-Facing Coatings

A new metal spray unit of improved design for applying hard-facing coatings in powder form is now available from Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich. The unit, which is called the Model C Spraywelder, is particularly adapted to the application of Colmonoy nickel-base wear and corrosion-resistant hard-facing alloys to steel, stainless steel and some cast-iron and copper-alloy parts by the Sprayweld process. In this process, the powdered alloys are first applied by spraying and then fusion-bonded to the part by heating with an oxy-acetylene flame.

Metallizing operations using copper, nickel, stainless steel, brass, lead and zinc in powder form can also be handled by the new unit.

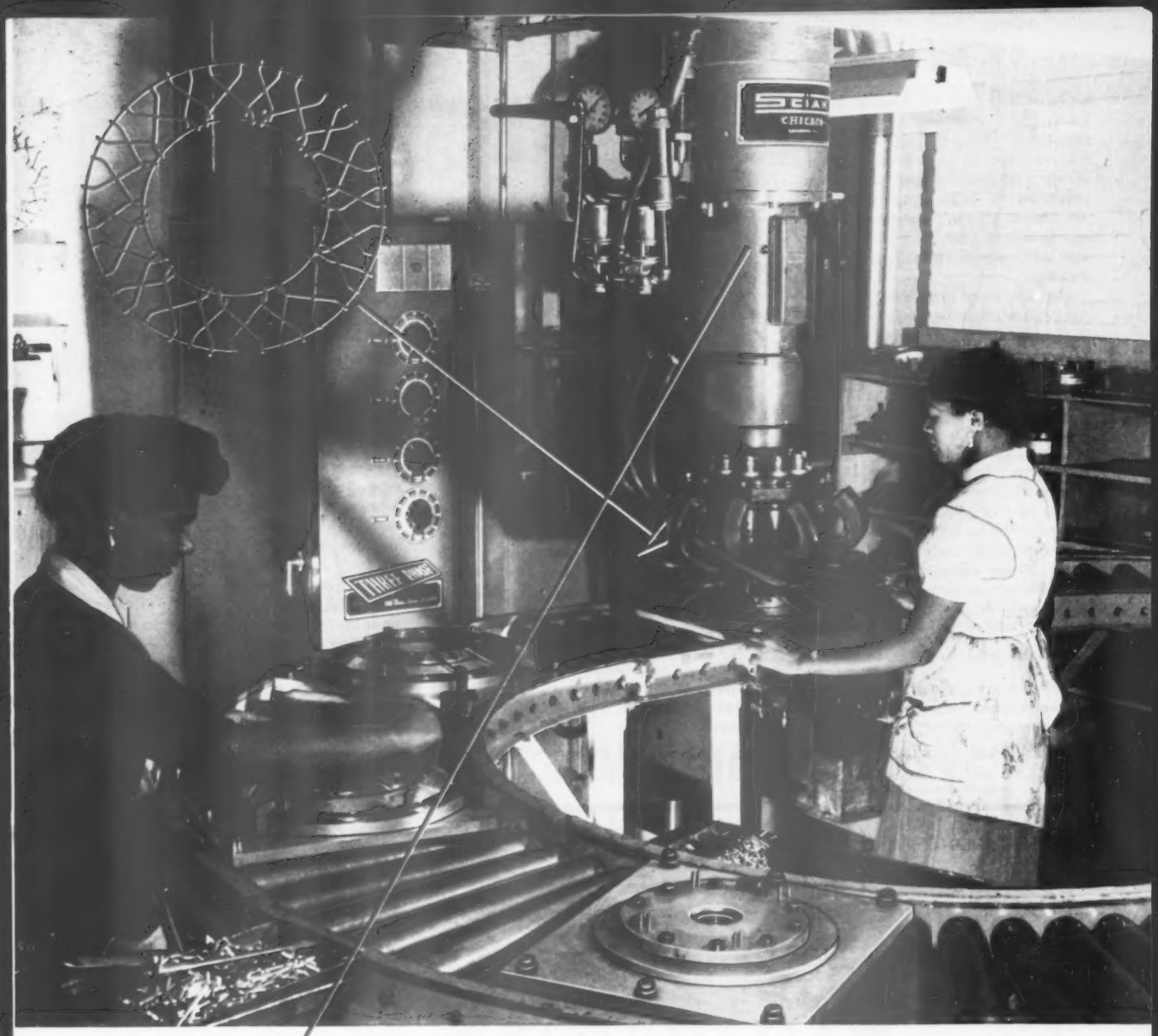
The Model C Spraywelder components are mounted on a crackle-finished panel that is either wall or pedestal mounted. These include a light-weight 3-lb aluminum pistol, a chromium-plated copper hopper, a cast brass carburetor, an air regulator, an air filter and suitable oxygen, acetylene and powder hoses and fittings.

To operate the unit, necessary connections are made to oxygen and acetylene tanks and a factory air supply capable of delivering 10 cfm of dry air at 60 psi minimum. The pistol can either be held in the hand for the spraying operation or mounted in a tool post holder on an engine lathe or turning fixture.

New Ceramic Backing Rings

The General Ceramics Corp. announces production of new ceramic backing rings that are easily removed when weld is complete; adaptable for both field and shop fabrication for faster and better welds.

These new rings assure complete but not excessive root penetration, prevent icicles, and weld "splatter." Completely re-



40 Spokes of .430 Stainless Resistance Welded to 2 Rings in Simulated Wire Wheels

CASCO PRODUCT'S (Bridgeport, Conn.) design of their complex, 42 piece wire wheel assembly presented serious problems of high production, allowable tolerances for positive fit, and cost of fabrication. Sciaky patented Three-Phase resistance welding provided most suitable answers to all requirements.

Two standard Sciaky welders complete the entire assembly in only four operations at a production rate of over a thousand per day. No skilled workers are required to produce assemblies that satisfy rigid inspection for alignment and set-down of welds. Sciaky Three-Phase produces smooth fillet welds eliminating special metal finishing. For complete details, write for R.W.A.W., Vol. 3, Number 9.

Resistance welding of Casco wire wheels is another fine example of Sciaky's basic thinking—welders designed to do *more useful work* at *lowest operating cost* with *maximum reliability.*

Largest Manufacturers of Electric Resistance Welding Machines in the World

SCIAKY

4919 West 67th Street, Chicago 38, Illinois

movable from pipe by flushing out shattered ring. Assurance of proper root penetration on every joint reduces "test failures," speeds welding operations and lowers cost of fabrication. Insulating properties of rings prevents chilling of weld metal, allowing complete penetration and fusion, permits lower welding amperage and allows more rapid acetylene welding.

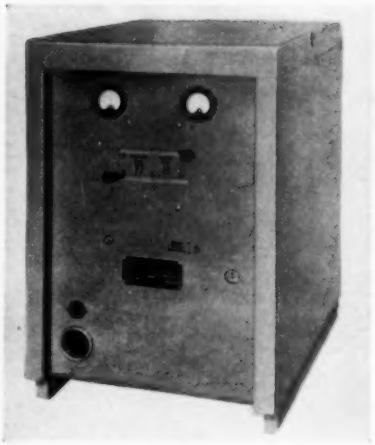
Ceramic rings form smooth, uniform, light beads inside the pipe. The grooves in the ceramic ring prevent excessive penetration and icicles since the welding arc cannot burn through the ceramic material. The resultant weld is smooth and uniform with a slight concave shape that provides maximum strength and minimum flow resistance. Rings with reusable positioner pins serve to center ring and act as root spacers while tacking joints.

The new rings are available in several types for various pipe applications.

Readers are invited to write for complete data. Please address: Chemical Equipment Division of General Ceramics Corp., Keasbey, N. J.

Constant Voltage Welder

Three new models of Glenn Constant Voltage welders for powering all metallic-arc automatic welding processes are now in production.



Improvements, based on nearly two years' experience with the original Glenn constant arc voltage units, include wider arc voltage range of 18 to 42 v, remote vernier control of arc voltage adjustment, increased rectifier capacity and simplified construction.

The three models have continuous-duty ratings of 500, 750 and 1200 amp, respectively, at 40 v. All operate from 208, 220 240, 440 or 480 v, 3-phase, 60-cycle power supply. Efficiency is 85% or better, power factor 90% or better, at all settings.

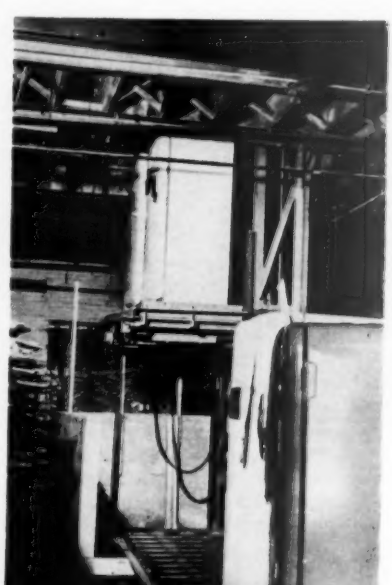
Original features of constant arc voltage, simplicity of installation and operation, absence of heavy moving parts to improve service life and reduce maintenance, are retained. No external voltage controls are required. On inert gas, submerged arc and semiautomatic processes, the arc voltage remains fixed at the desired voltage, feed and travel rates stay constant at the correct rate to produce desired deposit rate. The result is maximum simplicity of control and uniform welds.

Literature, prices and complete data can be obtained by writing Glenn Co., 3134 E. 10th St., Oakland 1, Calif.

Freight Elevators

Prefabricated electric freight elevators supported on welded steel columns independent of the building structure are being designed and manufactured by West Bend Equipment Corp. to aid in modernization of older factory buildings and warehouses.

The West Bend elevator engineers have developed standard Weld-Bilt elevator units that can be installed in any building, regardless of age.



Powerful, especially designed elevator motors lift or lower the platforms or cage at the rate of 39 fpm. Capacities range up to 4000 lb. The Weld-Bilt units are practical for lifts up to four floors and meet or exceed local safety codes

The entire bridge-like structure is compact and sturdy, fabricated of heavy structural steel arc welded throughout and braced with heavy steel cross bars. Sections can be added for future extended service and the entire unit can be moved to a new location.

Applications with normal call service or automatic operation are in use in several

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

AN AIR REDUCTION PRODUCT

FOR WELDING AND CUTTING...

IN THE RED DRUM

HIGHEST QUALITY

DUST-FREE

NATIONAL CARBIDE

Write for the name and address of the NATIONAL CARBIDE supplier nearest you.

National Carbide Company

GENERAL OFFICES: 60 EAST 42ND STREET, NEW YORK 17, N. Y.

A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED

...why GUESS about FLOW CONTROL?

...HAYS has REMOVED the guesswork!

ELECTROFLO VALVE

A solenoid valve for water or air. Provides *AUTOMATIC* control on fluid lines.

MESURFLO CONTROL

Flow Volume Control. *AUTOMATIC*. Maintains one set rate of flow regardless of variable inlet pressures.

SHUR-FLO AUTOMATIC INTERLOCK

Flow switch. *AUTOMATIC*. Protects equipment against an inadequate rate of flow.

ELECTROMITE VALVE

Small solenoid valve for low flow rates. *AUTOMATIC*. Available with flow volume control.

STRAITFLO STRAINER

Straight line strainer. *AUTOMATIC*. Protects equipment by providing clean un-interrupted flow.

HAYS controls give *AUTOMATIC* control for water and air!

HAYS flow controls are *ACCURATE, RELIABLE* and *AUTOMATIC*.

Our engineers will be happy to work with you on your flow problem. Write for folder No. 200 which describes our *AUTOMATIC* controls and gives technical information.

INDUSTRIAL SALES DIVISION

HAYS MANUFACTURING COMPANY

810 WEST 12 ST., ERIE, PENNSYLVANIA.

Complete *AUTOMATIC* Control. Establishes maximum flow rate —*AUTOMATIC* On and Off—Protects Equipment against inadequate rate of flow.

types of industry. Further information is available from West Bend Equipment Corp., 349 Water St., West Bend, Wis.

Hardening Steel Gears and Sprockets

A new method of case hardening gear and sprocket teeth at the same time they are being machined, and which permits close control over depth as well as area of hardening, is announced by the Cogmatic Co., Milwaukee, Wis. The process employs a combination of (1) flame preheat, (2) flame machining of toothed form and (3) quenching, all in one automatic operation.

Specially developed quenching methods make it possible to localize hardening to portions of teeth having greatest wear, while leaving other areas, such as tooth tips, tough and less susceptible to breakage. Tests show, for example, that hardness can be varied from 30 to 55 Rockwell Hardness C between the point and root of a 2-in. pitch tooth.

By preheating ahead of the cutting flame, the Cogmatic process is said to increase depth of case hardening to at least $^3/_{16}$ in., resulting in greatly increased wearing life. Preheat is accomplished by means of auxiliary torches.

Since both cutting and heat treating are automatic, the Cogmatic method is ideally suited to production manufacture, and exact duplication of parts. All Cogmatic flame-cutting machines can be equipped for automatic heat treating. Details are available from Cogmatic Co., 1330 N. Franklin Place, Milwaukee, Wis.

Welding Positioner

A new type, bench-model welding positioner (available with hand or power table tilt) has just been intoduced by the American Equipment Co. of Paterson, N. J.

The maker claims that the AECO positioner is engineered to create a superior method of positioning work for efficient and economical downhand welding. It is designed for smooth, dependable, full-range movement of work. . .with reversible, variable speed adjustment under full control of the welder. It is fabricated to machine tool standards of precision and built for a long life of dependable, trouble-free service.

This new American welding positioner is equipped with a gear type fluid drive motor and delivers smooth, positive hydraulic power at an efficiency approximating 80%. It operates on 110 v, ac, 60-cycle current. An infinite range of speeds is provided through one simple control with extra low "creeping speed" for certain welding operations. Work up to 100 lb

WHY BE ALMOST RIGHT . . .

There's an "exact" Westinghouse Electrode for your specific job

FREE samples on request

Try a quality Westinghouse Electrode on your toughest job. Ask for a free sample from your Westinghouse Welding Distributor, or use coupon below.

FREE electrode manuals

These helpful guides can save you welding dollars. Send for your copies today.

J-21851

Your choice of 51 electrodes	
TYPE	SELECTION
Mild Steel	9
Low Alloy Steel	4
Cast Iron	3
Stainless Steel	30
Hard Surfacing	5

YOU CAN BE SURE...IF IT'S Westinghouse

☐ B-6070 Complete Line Electrodes
☐ B-6076 Cast-Iron Electrodes
☐ B-6077 Stainless Steel Electrodes
☐ B-6078 Mild Steel Electrodes
☐ Free electrode samples
☐ B-6129 New RA Welder

WESTINGHOUSE ELECTRIC CORPORATION
Welding Department
P. O. Box 868, Pittsburgh 30, Pa.

Name_____
Company_____
Address_____
City_____ State_____

WJ-4-54

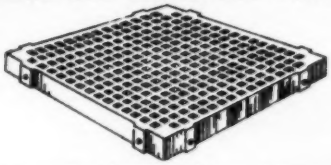
Buy "PROVEN FLUXES"
Years of GUARANTEED SATISFACTION
behind these GOOD
"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

WELDING and ASSEMBLY PLATENS



Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks — blacksmith blocks. 5'x5' — 6'x6' — 6'x8' — 6'x10' — 5'x10' — 6'x12' — 3'x3' — either 6" or 7" thick.

STAHL EQUIPMENT CO.
94 Washington St., Brookline Village 46, Mass.

or more, in size, is handled by the AECO positioner which has a full 135-deg vertical tilt (self-locking at any angle) and table rotation at any required speed.

The positioner is made from standard, easily replaceable parts. There is never any need to send to the factory for parts, never any costly delays of weeks or months waiting for service on parts available only from the original source.

Readers may write to the American Equipment Co., Dept. 15, 7 Albion St., Paterson, N. J., for a free descriptive folder. Dealer inquiries, too, are invited.

Heliweld Holder

A new light-weight, water-cooled Heliweld holder has been produced by Air Reduction for welding thin gages of aluminum, stainless steel, copper base alloys, magnesium and killed steel. It is specifically designed for manual Heliwelding in the aircraft, home appliance and automotive industries.

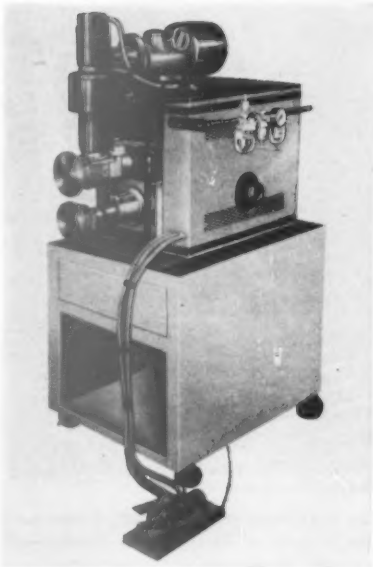
Known as the Airco H12A, this new fabrication tool's insulation material is constructed of a tough plastic, to withstand the roughest treatment. Its light weight and well-balanced design permit continuous use with a minimum of operator fatigue, and its compactness makes it easy to manipulate in hard-to-get-at corners.

The H12A is completely water-cooled for dependable and safe operation, providing the utmost protection from overheating in confined working areas.

Other features include interchangeable electrode caps 2-, 3- and 7-in. lengths; an assortment of ceramic nozzles designed to prevent arc-shorting in tight spots; a ruggedly constructed 12-ft long water-cooled cable assembly; four sizes of collets to accommodate 0.020-, 0.040-, $^1/_{16}$- and $^3/_{32}$-in. diam tungsten electrodes; and gas-tight sealing rings at the vital points to insure low operating costs.

The Airco H12A holder is rated at 125 amp and can be operated on a-c or d-c power. The holder measures $7^1/_2$ in. in length and weighs only 4 oz.

For further information on the H12A holder and for all the details on the complete line of manual, semi- and fully automatic Heliwelding equipment, request a copy of catalog 2300 by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.



Bench Type, Resistance Welder

A new, bench-type seam welder, recently released for production by the Dyer Weld Co. of Kansas City, Mo., is meeting with popular acclaim wherever it is shown. It is designed and engineered to meet the demand for a portable unit that will give maximum efficiency with a minimum of current.

An exclusive super feature is the new, improved, electrode shaft bushings, designed to convey 95% continuous current to the rollers and work, regardless of wear, insuring a uniform flow of current at all times to the material being welded. Another outstanding feature of this machine enables it to be converted to spot welding, by installing the spot welding attachment, thereby permitting the same machine to serve a dual purpose.

Any pressure desired may be applied on the work by the regulator-controlled, double-acting air cylinder, mounted directly to the upper roller head assembly.

Travel speed is controlled by a regulator control which permits travel speed of 1 to 30 fpm.

The transformer, 25 to 500 kva, is specially designed to carry a continuous load without heating and can be furnished for either single- or three-phase welding. All electrical controls are by General Electric.

Soldering Torch

A new "Torch-O-Matic," pistol-shaped torch for soldering, burning, sweating and other jobs, is designed for use with propane gas, according to the Velocity-Power Tool Co., Pittsburgh, Pa.

A squeeze of the trigger produces a controlled flame—a fine, pin-point or a full, 6-in. flame, as desired for any job—and

Advertising Rates

The Welding Journal

Effective March 1, 1953	1 time	3 times	6 times	12 times
Full Page	$255.00	$235.00	$220.00	$200.00
Two-thirds Page	180.00	165.00	155.00	145.00
Half Page	140.00	130.00	120.00	110.00
One-third Page	110.00	100.00	95.00	90.00
Quarter Page	85.00	80.00	75.00	70.00
One-sixth Page	65.00	60.00	55.00	48.00
Eighth Page	52.00	48.00	42.00	38.00
Special Preferred Position: (Full Page)	280.00	260.00	245.00	225.00
COVERS (12-time contracts)				
2nd Cover				$250.00
3rd Cover				230.00
4th Cover				270.00

WELDING ENGINEER

Graduate metallurgist with experience or interest in resistance welding to conduct welding and brazing research and development in the fields of ferrous and nonferrous metals. This is an outstanding opportunity for professional growth in an expanding research organization.

Liberal employee benefits include the opportunity for tuition-free graduate study. Send resume to:

J. F. Collins,
ARMOUR RESEARCH FOUNDATION
of Illinois Institute of Technology, Technology Center, Chicago 16, Illinois

the new torch saves substantial time and gas because of its instant-on, instant-off features, the announcement explains.

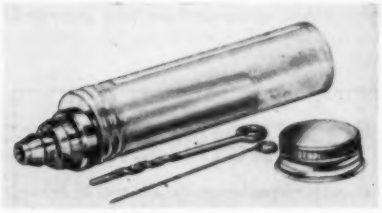
Electricians, plumbers, roofers, farmers, hobbyists, dentists and other users can get as much as 50% more time from a tank of propane gas because the flame snaps out on release of the trigger, it is pointed out. Absence of lingering flame on shut-off also promotes safety, avoiding accidental fires and burns.

The new Propane Torch-O-Matic connects directly to the propane tank, without need for intermediate valve apparatus.

Complete details are available on request, without obligation, from the Velocity-Power Tool Co., 201 N. Braddock Ave., Pittsburgh 8, Pa.

Packaging Tips

Something new in packaging tips for cutting torches—a plastic tip container—has just been introduced by National Cylinder Gas Co., Chicago.



According to the company, one of the chief causes of cutting tip failure is the damage sustained by tips *when not in use.* Unprotected tips that are stored loose in tool boxes or carried about in pockets are said, in many cases, to absorb far more punishment than when in actual use. And when the precisely machined seating surfaces become scored or nicked, tips either fail completely or operate at less than top efficiency.

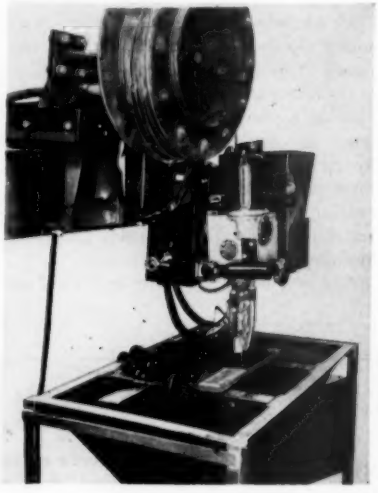
To prevent this costly and unnecessary damage, tips for NCG's Torchweld Cutting Torch are now available packaged in special protective plastic containers. Included in each container are two tip cleaners for the high-pressure oxygen and the preheat orifices.

NCG calls it new tip packaging "two-way tip protection" because (1) the container itself—which becomes a permanent storage place for the tip—guards the tip from damage as well as contamination by grit, grease or oil, and (2) the right tip cleaners are always handy to encourage proper cleaning of gas passages.

Such protection and maintenance, according to NCG, will immeasurably lengthen the useful life of cutting tips and correspondingly reduce their cost.

Spreadarc

The Lincoln Electric Co., Cleveland, Ohio, has announced new automatic welding equipment for producing beads up to 4 in. wide in a single pass. The equipment, called Spreadarc, is an attachment that mounts on a standard Lincolnweld automatic head and oscillates the head back and forth at right angles to the direction of travel. The amount of oscillation can be controlled to produce a pad of weld metal up to 4 in. in width in a single pass. It may be used to build up a layer of hard-surfacing metal or to build up with mild steel. Under proper conditions it may also be used to overcome poor fit-up conditions encountered in welding a joint.



The Spreadarc may be installed on Lincolnweld heads now in use without any major changes required. It is powered by its own variable-speed electric motor which through an eccentric oscillates the entire welding head assembly. The width of the oscillation is controlled by an adjustment of the eccentric and the number of oscillations per minute by a rheostat control of the motor speed. Speed and width are controlled to meet varying requirements. The Spreadarc may be turned off completely when normal straight welding beads are desired.

Hard surfacing with this equipment employs the hidden arc welding process and retains all the advantages of speed, uniformity and economy normally associated with the process when used for normal joint welding. Automatic hard surfacing can be applied to flat and round surfaces. The speed of welding compared to hand welding has been increased in production jobs by as much as 80%. Both maintenance and manufacturing original equipment can use automatic hard surfacing. Typical applications are scraper blades, tractor shoes, crusher rolls, shovel and dredge parts, hammers, crane ways, dipper teeth and bowl mills.

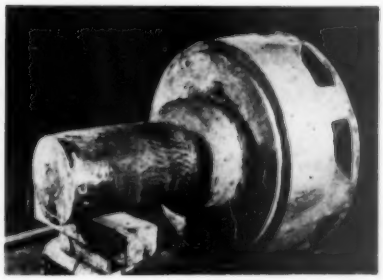
Spreadarc is normally used in combination with multiple arc welding using two small wires in place of one larger wire. The two wires and the resulting two arcs increase the size of the weld crater, reduce penetration while increasing deposition rate. The twin wire adaptation can be made to any standard Lincolnweld automatic head. Using only one wire with Spreadarc increases the amount of penetration and is used in hard-surfacing applications where this is desired.

Fluxes normally used with Spreadarc for hard surfacing are "agglomerated" alloy fluxes. A mild steel or medium carbon wire is used, the alloys being added to the weld metal through the fluxes in the crater. Agglomerated fluxes create a uniform, dependable deposit and can be readily varied to create a deposit to match different service requirements.

Electrode for Manganese Bronze

Bronze-Arc Mn, a new, patented electrode for welding manganese bronze, has been added to the line of electrodes made by Alloy Rods Co., York, Pa.

Bronze-Arc Mn electrodes, exclusive with Alloy Rods Co., are used for the fabri-



This 2000-lb manganese bronze casting had areas of excessive porosity in the as-cast condition. Bronze-Arc Mn was selected for the repair because good color match, machinability and soundness were important. The casting passed X-ray tests after repair with Bronze-Arc Mn.

Want D-C Welding at its best?

Get Sureweld® D-C Rectifier Arc Welder for easier welding, lower power costs and a lot less maintenance

When you see the Sureweld D-C Rectifier Arc Welder in action, you will agree that this is D-C welding at its best. It means *easier* welding because the unique transformer-reactor-rectifier unit provides welding current with outstanding arc stability at all current settings . . . with no "fading," with a minimum of arc blow, with instant recovery after shorts. Output current is modified at will by means of the easy-to-operate dial type control. There's a wide range of current available in every size of welder.

Sureweld means lower power costs because of high electrical efficiency, good power factor rating. Little power is consumed while welder is idling. There's no heavy starting current inrush.

It means less maintenance because there are no moving parts in the operating assembly, no bearings, brushes, commutators to wear out or get out of order. The Sureweld is so outstanding you must see it in action. Your authorized NCG dealer or your local NCG office will arrange a free demonstration. Or mail the coupon below for descriptive literature.

NATIONAL CYLINDER GAS COMPANY
840 N. Michigan Ave., Chicago 11, Ill.
Branches and Dealers from Coast to Coast

FEATURES THAT MAKE SUREWELD YOUR ONE BEST BUY

1. **Powerful Heavy-Duty Cooling Fan** keeps temperatures on all windings and rectifier well below safe limits.
2. **Safety Recessed Control Panel** houses all controls.
3. **Selenium Rectifier Stack** of sturdy, heavy-gauge metal plates, extra large in surface area for maximum cooling of rectifier.
4. **Thermostat** protects rectifier and transformer from abnormal heating.
5. **Lifting Hooks** permit easy, safe hoisting of welder.
6. **Exclusive Transformer Design** (patent applied for). Rectangular unit with extremely low center of gravity.
7. **Sturdy Drip-Proof Cabinet** has flush-front construction and recessed control panel.

NCG®
EVERYTHING FOR WELDING

Copyright 1954, National Cylinder Gas Company

National Cylinder Gas Company
840 N. Michigan Ave., Chicago 11, Illinois

☐ Please send illustrated Bulletin NH-114 containing full details of new Sureweld D-C Rectifier Welder.
☐ I am interested in a demonstration.

Name_____
Firm_____
Address_____
City_____ Zone__ State_____

cation and repair of manganese bronze without the need of high preheating temperatures necessary with other processes. This elimination of high preheating and interpass temperatures also eliminates a major cause of distortion and warpage.

Bronze-Arc Mn electrodes produce welds with an excellent combination of high strength, ductility and soundness. Tests prove that the physical properties of the weld deposits are equal to or better than plate material of the same type and with basically the same chemical composition.

Alloy Rods Co.'s new Bronze-Arc Mn electrodes will be widely used in the repair and reclamation of manganese bronze ship propellers. The low preheating temperatures required for welding with these electrodes make such repairs practical. In addition, Bronze-Arc Mn is being used to weld such manganese bronze castings as gears and pumphousings, impellers, mixer beaters, gears and worms and valves. Welding fabrications from plate are also practical when Bronze-Arc Mn electrodes are used.

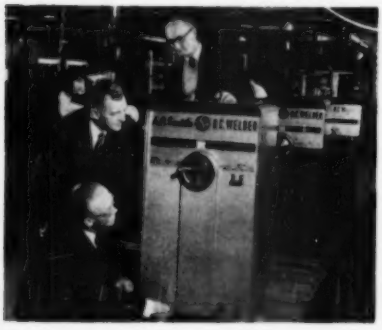
For additional information on new Bronze-Arc Mn electrodes, write: Alloy Rods Co., 5160 Lincoln Highway West, York, Pa.

Smith Welding Division

A highly mechanized production line which makes extensive use of overhead conveyor systems as well as roller runways underfoot is featured in the A. O. Smith Corp. Welding Products Division's expanded plant at Elkhorn.

A. O. Smith recently moved its entire production of welding machines from Milwaukee to this nearby Wisconsin community.

With the arrival at full production in the new quarters, the Welding Products Division has doubled output of welding machines over the volume in its Milwaukee operation. This enables the company to better serve increasing demand from its customers for the newly designed line of a-c and d-c welding equipment.



Nearing the end of the production line at the A. O. Smith Corp.'s new welding machine plant at Elkhorn, Wis., are some of the 400-amp. d-c welders made there. Looking over the product are R. S. Saddoris (kneeling), Director of A. O. Smith Quality Control; Ernest Kiewitt, Manufacturing Superintendent at the Elkhorn plant; and Paul Mederich, Plant Manager. The company's Welding Products Division operates the plant

Utilizing Scrap Sheet Titanium

By resistance spot welding a thick stack of these sheets submerged in liquid, a solid ingot of virgin metal is formed which is at least as strong as the parent metal. This ingot can then be machined into scarce hardware or aircraft parts.

The Martin Aircraft Co. process is basically unchanged from the normal method of resistance welding. By adding a tank to the machine in which the two electrodes and the material to be welded meet in liquid, it was found that the capacity of the machines could be increased up to sixfold. In the past, when metal was stacked more than an inch thick, it would seriously oxidize and become so hot as to cause metal expulsion and warpage. By performing the welding cycle under the cooling effect of a liquid, the thickness of the weldable laminate has been increased to 6 in. for titanium and 3 in. for stainless steel. Research is presently underway to increase these figures.

The applications of the new process are many. Perhaps one of the major items centers about the utilization of scrap titanium sheets generated in the manufacture of aircraft parts from this scarce material. Because titanium costs up to twenty dollars a pound and sells as scrap for one dollar a pound, it is obvious that great savings will be achieved. By this Martin process it is possible to resistance weld this scrap in stacks up to 6 in. thick. The nugget formed by the weld can then be machined into titanium hardware and aircraft parts. The scarcity of titanium hardware today and its high cost is well known.

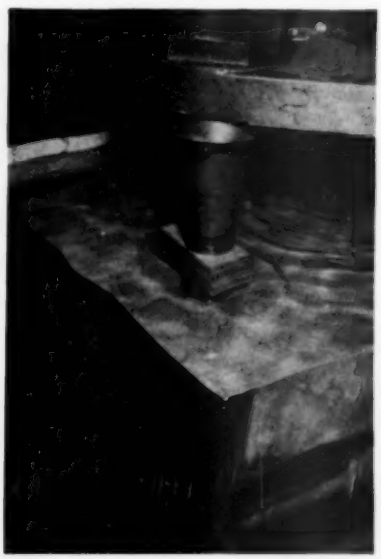


Fig. 1 A close-up of the tank constructed by The Glenn L. Martin Co. to develop the new resistance-spot-welding process

Visible is the lower electrode in the bottom of the tank, a stack of sheet stainless steel and the upper electrode. Through the use of this liquid coolant it is now possible to weld sheets of steel in thicknesses up to 3 in. and titanium in thicknesses up to 6 in.

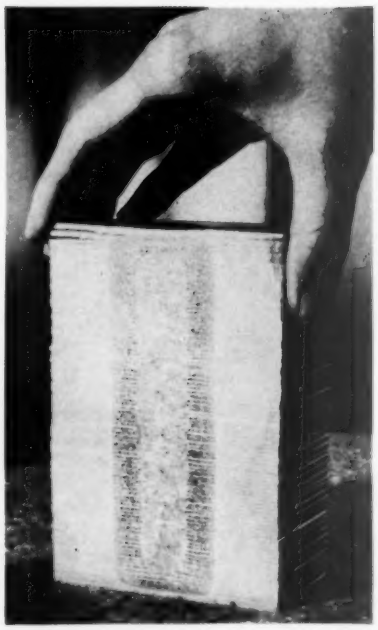


Fig. 2 Shown are 89 sheets of titanium that have been resistance spot welded in solution to form a solid stack 6 in. thick

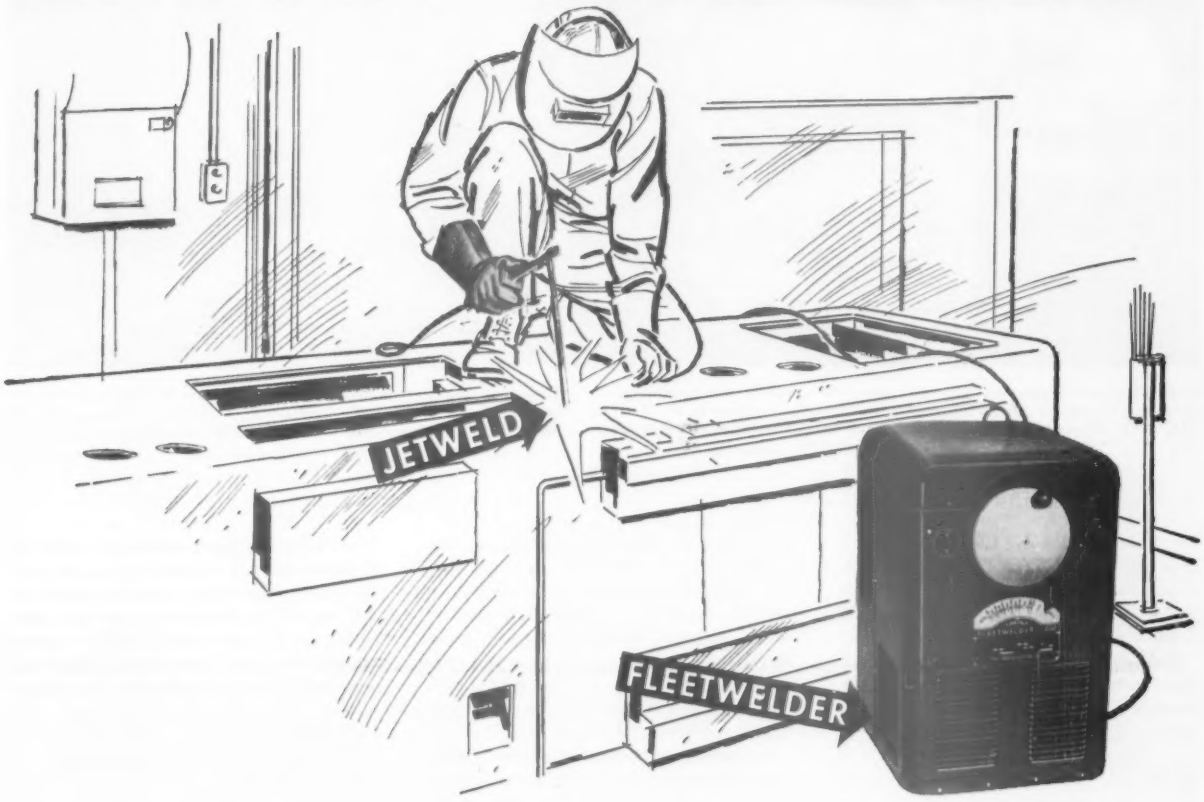
New Western Electrode Plant

The Alloy Rods Co., General Offices and Plant, York, Pa., formally dedicated its new Pacific Coast Division Manufacturing Plant located at 750 Lairport St., El Segundo, Calif., on Thursday, Feb. 18, 1954.

Several hundred Los Angeles people interested in the art of welding attended. Included in the group were many prominent figures in the Welding Industry. The plant was open to all guests. For most it was their first opportunity to see an arc-welding electrode manufactured by the extrusion process. This is the first electrode plant in the West that will produce a complete line of alloy arc-welding electrodes.

The company manufactures six complete lines of electrodes identified by trade names as follows: Arcaloy Stainless Steel

LINCOLN "JETWELDING"



...industry's greatest team for low cost, high speed hand welding

Lowest manual welding costs are achieved with "Jetweld", the high speed welding electrode developed and introduced by Lincoln, and "Fleetwelder"—Lincoln's AC transformer-type welder.

For the first time, "Jetweld" utilizes powdered metal in the electrode coating... enabling use of higher currents to speed welding. Iron powder becomes an additional source of metal for the weld. Welds are more uniform, free of undercut, of X-ray quality.

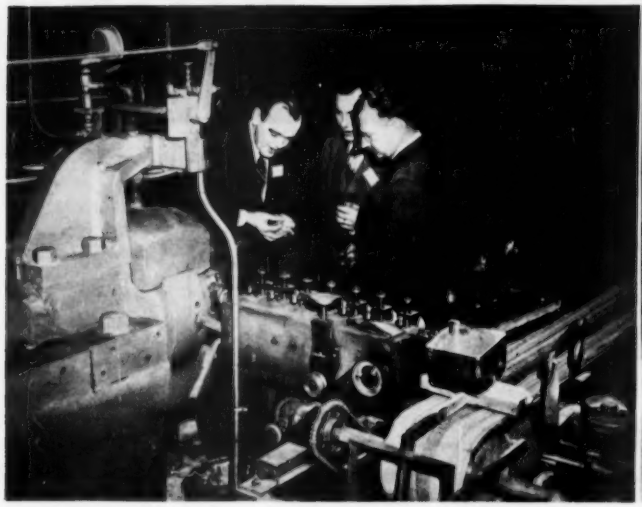
THE RESULT: Average increases in speed of 35%... *and more.*

CHECK LINCOLN'S NEW LOW PRICES Lincoln's new combination of lower AC machine prices and faster welding with "Jetweld" can cut your welding costs. See for yourself. Have your Lincoln representative check your requirements for electrodes and welders. Call or write.

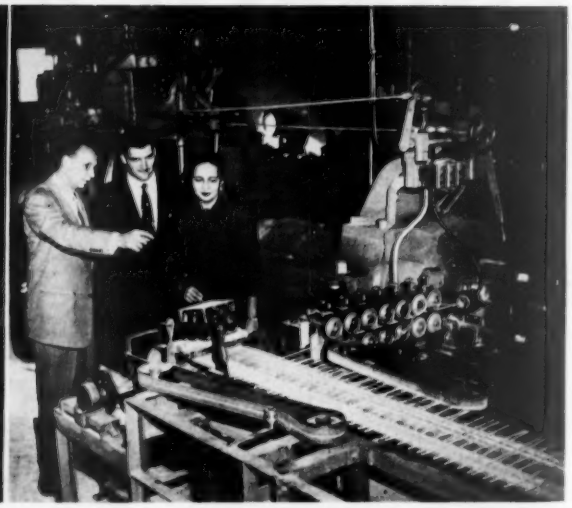
THE LINCOLN ELECTRIC COMPANY

Dept. 1705
CLEVELAND 17, OHIO

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT



Explaining the necessity of the correct coating consistency for proper extrusion of the electrodes. Left to right—E. R. Walsh, III, T. D. Aller, Southwest Welding & Mfg. Co., Marvin Pearson, Southwest Welding & Mfg. Co.



Explaining the operation of the extrusion press is left to right—E. J. Brady, J. Williams, Student, University of Southern California and Joan Brady, Student, University Southern California

Electrodes, Nickel-Arc Electrodes for Cast Iron Welding, Wear-Arc Hard Facing Electrodes, Bronze-Arc Bronze Electrodes, Tool-Arc Tool and Die Electrodes, and Weld-Arc Low Hydrogen Electrodes.

Present from the home plant in York, Pa., were the following executive personnel: E. J. Brady, President, M. G. Sedam, Executive Vice-President, R. K. Lee, Vice-President—Research, E. R. Walsh III, General Sales Manager, and F. L. Blodgett, Assistant General Sales Manager.

George M. Hohmann is Plant Manager of the new manufacturing plant. The plant is designed as a custom plant to care for the alloy welding electrode needs of the many diversified Western industries including Aircraft, Metal Fabricating, Petroleum, Chemical, and Paper. The Pacific Coast Division sales and manufacturing facilities will service Alloy Rods Distributors in the eleven western states.

Acetylene Generator

Acetylene is delivered continuously, without interruption for water changes, residue removal or carbide recharging by the new Oxweld MP-11 Acetylene Generator. The MP-11, developed and introduced by the Linde Air Products Co., a Division of Union Carbide and Carbon Corp., generates just enough gas to meet immediate demand from consuming equipment, even though this demand fluctuates over a wide range. The MP-11 has a rated hourly output of 1000 cu ft, with higher delivery rates available for shorter, intermittent periods.

Efficient and economical, the MP-11 has automatic controls and practical safety devices that reduce operating costs. Generation of acetylene is continuous. No standby generator is required for periods of carbide recharging, residue removal or water changing. In most cases the MP-11 will do the job of two conventional generators. For an 8-hr period, it will actually deliver 8000 cu ft of acetylene at a pressure of 13 psi.

Simplicity of design and heavy-duty construction insure trouble-free operation and minimum maintenance costs.

Carbide feeding is automatically adjusted to consumption demands. A pressure-tight charging hopper attaches easily to the top of the generator to permit safe, air-free carbide charging without interrupting acetylene production. There is never any question about when to recharge since an easy-to-read indicator clearly and accurately shows the weight of unused carbide in the generator at all times.

Every important safety feature is incorporated. Water automatically shuts off at the correct level to prevent overfilling. If the water level becomes too low, carbide feed automatically stops. A hydraulic back-pressure valve prevents any reverse flow of acetylene from the service line. The MP-11 has been accepted by Underwriters' Laboratories, Inc., for listing under its Re-examination Service.

The new Oxweld MP-11 Acetylene Generator is delivered as a compact unit ready to be installed. It occupies a floor area of 60 in. in diameter. Height of generator, with charging hopper attached, is 14 ft. Total dry weight of generator is approximately 2050 lb.

Huge Reactor Unit

The design of the M. W. Kellogg Catalytic Reformer, based on Lukens Steel Co. big plates, will catalytically reform a record 30,000 barrels of low-octane petroleum fractions daily to high-octane motor and aviation gasolines in a midwest Refinery.

Big "orange-peel" section plates of carbon-molybdenum steel, rolled and formed by Lukens Steel Co. of Coatesville, Pa., for the bottom head of one of the largest and heaviest reactor vessels ever built, are joined together in the shops of

Huge Reactor Unit

its designer, the M. W. Kellogg Co. at Jersey City, N. J. The size of these and other Lukens plates saved many feet of welding in the 1.3 million-pound unit that will form the heart of a record 30,000-barrel-per-day fluid catalytic reformer for a large midwest petroleum refinery. Topped by a smaller processing vessel, the completed installation will be over 200 ft high. Too big to be shipped complete, the finished unit will be transported in knocked-down sections to the erection site.

Airco Easyarc 12 Electrode

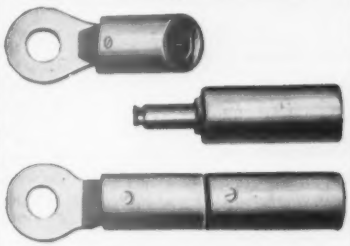
In Buffalo, N. Y., at the AMERICAN WELDING SOCIETY sponsored Welding and Allied Industries Exposition, Air Reduction demonstrated their newest type of welding electrode, the Easyarc 12. According to the manufacturer, this new electrode welds mild steel at speeds doubling those obtained with conventional electrodes.

The reported increase in welding speed is attributed to the addition of powdered metal to the electrode coating. This changes the arc action so that welds can be made by dragging the electrode in contact with the plate. Because the metal powder becomes part of the weld bead, faster welding is achieved. Weld spatter is decreased to less than half that obtained with regular electrodes.

The weld beads are exceptionally smooth and the weld metal is of high strength, good ductility and sound X-ray quality.

Airco "Easyarc 12" is recommended by the manufacturer for the fabrication of mild steel involving plate and rolled sections.

TWECO TERMINAL CONNECTORS
for Welding Machines



Bolt directly to positive and negative welder studs. Provide easy cable switch to reverse polarity. Simple cable disconnect for quick "Jump-In" of additional cable.

3 Sizes for cables #6 through 4/0

The male plug of TWECO "Sol-Con" and "Mec-Con" Cable Connectors connect with TWECO Terminal Connectors Sol-Con and Mec-Con Cable Connectors are COMPANION ITEMS.

Write for Twecolog #9 giving data and prices on the complete TWECO line of electrode holders, ground clamps and cable connections for electric welding.

See Your Welding Supply Distributor

Tweco PRODUCTS COMPANY

TWECO PRODUCTS

Boston at Mosley WICHITA, KANSAS

1954 AWS
National Fall Meeting
November 1–5, 1954
Sherman Hotel, Chicago, Illinois

LIST OF NEW MEMBERS

Effective March 31, 1954

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ARIZONA

Cornelius, Johnny F. (C)
Nance, James M. (C)
Stacy, J. F. (C)

BIRMINGHAM

Davis, William L. (B)
Temerson, Abe (C)
Wilder, J. D. (B)

BOSTON

Duggan, Earl (B)
Blank, Russell (C)
Brown, C. W. (B)
Daley, Daniel M., Jr. (C)
Gilchrist, Alan D. (B)
Morrison, Robert (B)
Prescott, Edward T. (C)
Sardella, William F. (C)

BRIDGEPORT

Spiers, Arthur E. (B)

CHATTANOOGA

Gray, Harold N. (B)

CHICAGO

Einbecker, Thomas J. (B)
Gerl, Anthony J. (B)
Katilavas, Frank A. (B)
Linn, Thomas B. (B)
Martin, Vernon F. (B)
Milner, Howard E. (B)
Olliges, James R. (B)
Wendorf, Albert L. (B)

CINCINNATI

Levinstein, Moses A. (C)

CLEVELAND

Hildebrand, Carl Robert (B)
MacPherson, Bruce M. (C)
Prater, James C. (C)
Shutt, Robert C. (C)
Warnes, C. E. (C)
Welf, Robert H. (B)

COLUMBUS

Appel, Donald V. (D)

DALLAS

Foote, Harold E. (C)

Jenkins, Paul R. (B)
Picard, Denny (C)

DAYTON

Bell, Charles W. (C)
Fontaine, John (B)

DETROIT

Burges, Cameron A. (B)
Davis, George F. (C)

HARTFORD

McLaughlin, John M. (C)

HOUSTON

Boydston, Charles E. (C)
Caldwell, J. D. (C)
Camp, Harold Lee (D)
Denmark, Marion A. (B)
Feigelson, Harold A. (B)
Forbus, James Douglas (B)
Hardcastle, H. A. (B)
Hardy, Henry Walter, Jr. (B)
Hines Earl H. (B)
Hodges, Cal (B)
Husted, R. A. (C)
Johns, Ray William (B)
Johnston, H. R. (B)
Jones, Jack P. (D)
Jonte, George D. (C)
Keith, Otis Alvin (C)
LaFleur, R. A. (B)
LaFleur, Sidney O. (B)
Marshall, Fred B. (C)
McGown, James W. (D)
Montoya, Fred T. (C)
O'Brein, Robert J. (B)
Seale, Jack (C)
Shira, R. A. (C)
Smith, Albert H. (B)
Stuart, James E. (B)
Toal, T. H. (C)
Truett, A. T. (B)
Williams, E. J. (C)
Williams, Michael J. (B)

INDIANA

Moulton, Charles F. (C)

IOWA-ILLINOIS

Schebler, Edward A., Jr. (C)

KANSAS CITY

Looney, Lewis L. (C)
Warn, James R. (B)

LEHIGH VALLEY

Berka, William, Jr. (B)
Murphy, William J. (C)

LONG BEACH

Ferguson, Robert A. (B)
Johnson, Harold E. (B)

LOS ANGELES

Applegate, Robert R. (C)
Cape, A. T. (C)
Goodin, H. A., Jr. (C)
Jones, Robert E. (B)
Kropp, William H. (C)
Lashbrook, Carl (C)
Omans, Roy Nelwin (B)
Remenyi, Joseph (B)
South, Virgil M. (C)
Webb, Arthur M. (B)

MAHONING VALLEY

Gatshall, Clark M. (B)
Rigo, M. A. (B)

MARYLAND

James, William Lamont (B)

MICHIANA

Frederick, A. C. (C)

MILWAUKEE

Hogan, Cornelius J. (B)
Jung, Robert A. (B)
Warner, David R. (B)

NEW JERSEY

Bruno, John N. (B)
Carlson, George L. (C)
Kelly, William A. (C)
Ocello, James (B)
Reilly, William E. (B)
Riordan, Leonard J. (C)
Scheller, Arthur P. (B)
Schroeder, Kenneth J. (C)
Semonchik, Andrew (B)

NEW YORK

Arena, J. F. (C)
Bekiaris, John (C)
Calhoun, Robert B. (C)
Cowdell, R. (C)
Crowley, J. (C)
Daisley, Roger E. (B)
Diorio, J. (C)
Farrell, Laurie (B)
Fernandes, Antonio L. (C)
Fisher, Henry G. (C)
Fredericks, Charles F. (B)
Giratz, E. (C)
Gordon, H. Robert (B)
Hammesfahr, Charles (C)
Harris, Roy (B)
Henne, C. (C)
Hodgins, Robert (C)
Holmes, John (B)
Hopkins, H. (C)
Hydrick, Oliver J. (B)
Jambor, Joseph F. (C)
Kold, Charles F. (B)
Leary, Herbert B. (B)
Lyden, K. C. (B)
Massa, J. H. (C)
McDonald, W. (C)
McGeary, Austin E. (B)
Miller, Fred (C)
Mitchell, Robert J. (B)
Morra, D. (C)
Moses, L. (C)
Mooney, Edward (B)
Muller, Jack (B)
Opisso, Larry J. (C)
Parisi, Joseph (B)
Preusse, C. (C)
Puff, Bernie, (C)
Ritchie, Walter W. (C)
Rizzo, Frank (C)
Saunders, Norman (C)
Schad, Joseph C., Jr. (C)
Scheifele, Ernst (C)
Schweitzer, Joseph (C)
Simkovich, Edward (C)
Smith, William E. (B)
Stone, Leo (B)
Suchanek, Charles (B)
Tafuri, Walter (C)
Tagg, John E. (B)
Trotter, Nicholas J. (B)
Tunison, John R. (B)
Van Kollem, Leonard (C)
Voelker, Charles H. (B)
Winters, F. J. (C)
Wolfe, T. M. (C)

NIAGARA FRONTIER

Baumler, Gerald A. (C)
Burke, Robert E. (B)
Dykins, Neil V. (B)
Forrest, Norman R. (B)
Gage, Robert M. (C)
Jesiomowski, Richard A. (B)
Tischendorf, Glenn (B)
Wachsmuth, George F. (B)

NORTHEAST TENNESSEE

Browder, N. L. (B)
Garrison, Howard (B)
Lewis, K. E. (B)
Marler, E. A. (B)
McCarroll, T. E. (B)
McGinnis, A. W. (B)
Scheiman, Adolph D. (C)

NORTHERN NEW YORK

Blum, Bernard Herbert (C)
Edwards, Richard H. (C)

NORTHWESTERN PENNSYLVANIA

Zandi, Carl A. (C)

OKLAHOMA CITY

Case, Coyle W. (C)
Edwards, Milburn Roth (C)
Kennedy, Ellis L. (C)
Short, Roy D. (C)

PASCAGOULA

Anderson Edward M. (C)
Puddington, C. G. (C)
Tapper, N. J. (C)
Terry, W. J. (C)
Williams, Paul (C)

PHILADELPHIA

Marshall, Robert C. (C)

PITTSBURGH

Collins, Thomas A. (C)
Duffer, J. C. (C)
Grabb, Edwin H. (B)
Matthiesen, R. B. (C)
Morgan, G. (C)
Thompson, J. (C)
Zucco, Elmer (C)

PORTLAND

Palm, Frank L. (C)
Sowles, Lawrence P. (B)

RICHMOND

Wiser, Handy O. (C)

ROCHESTER

Butterfield, Richard John (C)
Moulthrop, Livingston P. (C)

SAGINAW VALLEY

Curran, Donald (C)
Davis, Frank E. (D)
Pangborn, Samuel Kaye (C)
Reitsma, Louis J., Jr. (C)
Shoskey, Gerald J. (C)
Williams, Parker E., Jr. (D)

SAINT LOUIS

Bennett, Clarence (C)
Kirchner, James E. (C)
Salmons, Clarence H. (C)

SALT LAKE CITY

Despain, Leo F. (C)

SAN FRANCISCO

Doherty, William L. (B)
Sanchez Ray (D)
Wood, Charles C. (C)

SANGAMON VALLEY

Brady, Jim V. (C)
Davidson, Edison C. (C)
Gooch, James E. (C)
Maier, George J. (C)
Scherf, John G. (B)
Slaughter, J. E. (B)
Yeaman, Lester B. (C)

SUSQUEHANNA VALLEY

Arivese, Anthony (C)
Barrows, A. (C)
Bartlow, Aulden (C)
Curnow, Edwin (C)
Fenstermacher, Jack (C)
Martone, Peter (C)
Mitchell, Gove M. (C)
Montgomery, B. (C)
Murray, Thomas J. (C)
Nicholson, Stanley (B)
O'Neill, Edward A. (C)
Selige, John (C)
Sladicka, John (C)

SYRACUSE

Ribyat, Seymour (C)

TRI-CITIES

Donahue, K. T. (B)
Greenleaf, Wendell L. (C)
Malone, William R. (C)

TULSA

Dorsey, Walter (C)
Ingraham, R. H. (B)
Niemi, Edward T. (B)

WASHINGTON

Drevitson, Wesley B. (C)

WESTERN MICHIGAN

Diamond, James F. (C)
McKee, Gilbert Langdon (B)

WICHITA

Smith, Leo J. (C)

WORCESTER

Callette, Leo J. (B)
Parker, Aarne J. (B)

NOT IN SECTIONS

Cuervo, Ing. Raimundo (B)
Jarvis, Clarence A. (B)
Kruse, Arnold A. (C)
Mossa, E. G. (B)
Soria, Juan Cantor (C)

Members Reclassified

During the month of April

CHICAGO

Chase, Harry (C to B)

NEW JERSEY

Schnetzer, Siegfried (C to A)
Smith, Warren C. (C to B)

NEW ORLEANS

Nelson, Herman E., Sr. (C to B)

PITTSBURGH

Lovejoy, Ralph F. (C to B)

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Resistance Welding

Berwick, Pa.—On Apr. 7, 1954, the *Susquehanna Valley* Section was privileged to hear a talk on Resistance Welding by K. W. Ostrom, AWS, President of K. W. Ostrom and Co. of Philadelphia.

The subject, "Applications and Limitations of Resistance Welding," was excellently presented by Mr. Ostrom and was well received by the members and guests. The talk was illustrated with a mock-up diagram of the basic rocker-arm welder which was then developed into the more complex press-type equipment, and many actual sample welds were exhibited showing the applications of this welding process. This highly successful meeting was evidence of the high quality of Mr. Ostrom's talk which was void of any commercialism.

Annual Meeting

Boston, Mass.—The annual meeting of the *Boston* Section was held on April 12th at the U. S. Steel Supply Division Warehouse, Boston.

Preceding the meeting, over 250 members and guests were treated to a conducted tour of the warehouse and were able to see all the services which a steel warehouse performs.

After a cocktail hour, an excellent dinner was served by the caterer, Dora Ferguson.

The following members were elected for the 1954–55 season.

Chairman—Allen G. Hogaboom
First Vice-Chairman—Harry J. Ferguson
Second Vice-Chairman—Herbert Turck
Secretary-Treasurer—Hermon L. Toof
Trustee—P. Edward McKenna
Directors (for two years)—Harvey S. Miller, Andrew Kokolski, Warren Kulberg
Directors (for one year)—Harry Udin, Albert O. Wilson, Jr., Charles F. Peterson

The meeting was then turned over to the new Chairman who presented the Past-Chairman's Pin to Frank L. Brandt, Jr.

Following the business meeting, two extremely entertaining films were shown; "The New Fairless Plant" and "Cerro Bolivar."

Panel Discussion

Cleveland, Ohio—The April 14th meeting of the *Cleveland* Section was in the nature of a panel discussion. Ten experts answered questions from the floor as well as those submitted in advance of the meeting. Eighty-five members and guests were present at this panel.

Coffee speaker was Max B. Robinson, Dean of Co-operative Education at Fenn College and member of the Board of Governors of the Cleveland Engineering Society. Mr. Robinson presented the story of the new Cleveland Engineering Center located on the Northeast Corner of Carnegie and East 19th Sts. The building campaign is underway to raise $1,378,000 for the construction of this Center Building sponsored by the Cleveland Engineering Society.

Plant Tour—New Section Organized

Columbus, Ohio—The Marion Power Shovel Co., Marion, Ohio, was host to the *Columbus* Section for a tour through their plant for the regular meeting, Mar. 12, 1954. About 150 members and guests from Columbus, Toledo, Cleveland and north central Ohio were welcomed by John Courtright, President and General Manager of Marion Power Shovel Co. A. J. Busick, AWS, Vice-President of Engineering, explained the applications and advances in welding at the plant, in a short talk after dinner at the Hotel Harding in Marion.

Michael S. Shane, AWS, of the Cleveland Electric Illuminating Co. was the guest speaker. "From the Ponderable to the Imponderable" was the title of Mike's very entertaining talk based on the power production and distribution system of Cleveland, and the problems arising from welding machine loads. Mr. Shane is a member of the AWS National Board of Directors and with this background was able to follow his talk with some data and predictions on the growth of the AMERICAN WELDING SOCIETY.

The North Central Ohio Section of the AMERICAN WELDING SOCIETY was organized at a meeting of the Activation Committee preceding the plant tour. John Blankenbuehler, District 4 Director, and M. S. Shane and R. S. Green, Directors, were present and aided in the activation work.

The Executive Committee of the Columbus Section offered any assistance they could give, in a meeting held concurrently.

Mr. Blankenbuehler presided at the

Annual Meeting Boston Section Apr. 12, 1954. Photo courtesy U. S. Steel Corp.

regular meeting of the Columbus Section for the election of the new Section's officers who will be:

Chairman—Vincent Woodward, Lima
First Vice-Chairman—Robert A. Ellison, Mansfield
Second Vice-Chairman—Terry Long, Findlay
Secretary—Howard Cary, Marion
Treasurer—Solon McDonald, Mount Vernon

Nondestructive Testing

Columbus, Ohio.—The various methods for the nondestructive testing of metals, including welds, were described to the *Columbus* Section by Samuel A. Wenk on April 9th. Sam Wenk is chief of the nondestructive testing research at Battelle Memorial Institute. For the last three years he has been closely associated with research aimed at developing new methods for inspecting manufactured goods without destroying them. Sam illustrated the various nondestructive testing machines on the market today, described how each one worked and its applications.

Richard J. Anderson, Manager of Foreign Relations, Battelle Memorial Institute, gave a very humorous description of a trip he made several years ago to Africa.

The new officers of the Columbus Section for the coming year are as follows:

Chairman—Arthur Bruce
Vice-Chairman—Roger A. Zimpfer
Secretary—Roy McCauley
Treasurer—Joe Brockmeyer

Bridges and Buildings

Dallas, Tex.—R. B. (Bob) Reilly, AWS, of the American Institute of Steel Construction, Dallas, was the guest speaker at the March 24th dinner meeting of the *Dallas* Section held at the Delta Restaurant. Mr. Reilly's excellent presentation was on the subject "Shop and Field Welding for Bridges and Buildings."

Tooling for Welding

Dayton, Ohio.—The April meeting of the *Dayton* Section was held on the 13th at the Engineers Club. "Tooling for Automatic Welding" was the subject of a talk given by Anthony K. Pandjiris, AWS, President, Pandjiris Weldment Co., St. Louis, Mo. Mr. Pandjiris' talk dealt primarily with the proper outlook on the application of weld metal to a weld joint so as to effect maximum efficiency of welding. Slides were shown indicating jobs tooled for welding.

A color film "The Bulldog," showing work done at the Cadillac Tank Plant in Cleveland, was shown at the beginning of the program.

Annual Picnic

Dayton, Ohio.—The Annual Picnic of the *Dayton* Section will be held on June 15th at the Inland Activities Center.

ASME Code Vessels

Denver, Colo.—A nontechnical talk on "Prepare Your Shop to Accept Orders for ASME Code and National Board Vessels" was given by B. O. Williams of the Hartford Steam Boiler Insurance & Inspection Co. at the April 15th meeting of the *Colorado* Section.

Graham R. Miller, Assistant Superintendent, Denver Public Schools, was the coffee speaker. Mr. Miller gave an interesting talk on "Man and Materials."

Training Welders

Des Moines, Iowa.—The *Iowa* Section held their monthly meeting on Thursday, Apr. 15, 1954, at the New Pastime Club in Des Moines. There was a good attendance on hand to hear A. N. Kugler, AWS Chief Welding Engineer, Air Reduction Sales Co., speak on the subject "Training Welders."

Mr. Kugler, whose experience in training welders is exceptional, broke down his topic into various phases and established their purpose toward training the welders. He covered such phases as: What is your purpose; What are you trying to do in training a man; equipment needed; material needed for welding; what is to be taught in the course; instructions on related theory; safety; where one goes for its instructors; final examination; evidence of completing of the course; and who pays the bill.

Mr. Kugler's speech was well received and brought forth a long and interesting discussion period.

Quality Control

Erie, Pa.—The *Northwestern Pennsylvania* Section held its April dinner meeting on the 14th at Priscilla's Cape Cod Kitchen. An excellent semitechnical talk on "Weld Quality Control" was given by R. K. Allen, AWS, who is associated with the Laboratory of the Locomotive and Car Equipment Department of the General Electric Co.

A Travelogue film was shown through the courtesy of the Grise Film Library.

Special guest at the meeting was J. S. Blankenbuehler, Vice-President, District 4.

Alloy Electrodes

Fort Wayne, Ind.—The March 19th dinner meeting of the *Anthony Wayne* Section was held in Howard Johnson's. An excellent semitechnical presentation on the subject "Recent Developments in Alloy Electrodes" was given by R. K. Lee AWS, of the Alloy Rods Co., York, Pa.

Through the courtesy of the Allegheny Ludlum Steel Co., an excellent film, entitled "Stainless Steel Production," was shown before the meeting.

Plant Tour

Fort Wayne, Ind.—The *Anthony Wayne* Section and the *Michiana* Section jointly took part in a plant tour of the Bendix Products Automotive Division in South Bend on April 15th.

Annual Spring Conference

Grand Rapids, Mich.—Approximately 80 members and guests attended the Annual Spring Conference of the *Western Michigan* Section. This year the confer-

Annual Spring Conference Western Michigan Section

Standing (left to right)—Session Chairman: A. Turpin, Lansing Tank and Welding; E. MacDonald, Central Welding Supply Co.; W. McClellan, Purity Cylinder Gases; D. J. Harvey, Conference Director, Michigan State College; E. Guenther, Gibson Refrigerator. Seated (left to right)—Speakers: A. Clemens, Arcrods Corp.; C. Bruno, Reynolds Metals Co.; A. N. Kugler, Air Reduction Sales Co.; A. F. Wood, S-M-S Corp.; F. L. Plummer, Hammond Iron Works and National President AWS

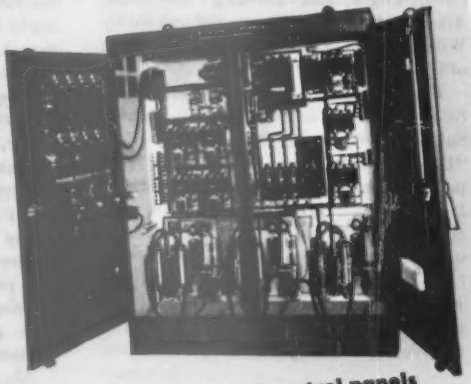
DESIGN LEADERSHIP

IN WELDER CONTROL FOR MASS PRODUCTION INDUSTRIES

A leading automobile manufacturer asked Square D to design magnetic and electronic control for a battery of 10 new multi-transformer welding presses. As many as 168 spot welds are made by one machine with 14 individually controlled timing periods in sequence.

Among the "must" requirements were:—welding current flow synchronized to prevent high starting transients and minimize stress on transformer windings; and a limitation of 1000 ampere current in each 3 phase line. *These 10 controllers are still providing trouble-free service after two years on the production line.*

Engineering counsel on any electrical control problem is available through Square D field offices in all principal cities.



One of the completed control panels *Because Square D's line of control is so complete, this entire unit was designed using only standard devices, accessories and electronic sub-assemblies.*

SQUARE D COMPANY

ence was held on April 9th at Michigan State College in East Lansing. The one-day conference featured morning and afternoon technical sessions covering resistance welding, aluminum welding, arc welding electrodes and brazing.

Arthur F. Wood, AWS, Vice-President of the S-M-S Corp., discussed dies and fixtures for resistance welding. Mr. Wood's talk covered standard and special dies and the material used in the manufacture of dies and fixtures used in resistance welding. Slides were used to show examples of special dies now in operation. Eric Guenther acted as chairman of the session.

Charles Bruno, AWS, Chief Welding Engineer of the Reynolds Metals Co., was introduced by A. Turpin who acted as chairman of the session on aluminum welding. Mr. Bruno discussed the latest methods of joining aluminum by welding, brazing and soldering. Slides were used to illustrate some of the fundamental problems encountered in aluminum welding such as oxides, heat conduction and weld metal characteristics. Some of the newer aluminum welding processes such as inert gas and cone arc were discussed.

Before the afternoon session, Douglas J. Harvey, Conference Director, Introduced Fred L. Plummer, National President of the AMERICAN WELDING SOCIETY. Mr. Plummer gave a short talk on the national technical meetings that will be held this year by the AWS.

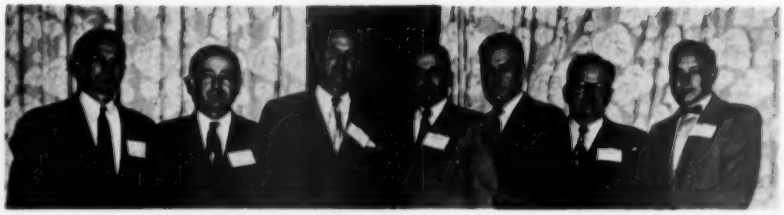
In the first afternoon session A. Clemens, AWS, of the Arcrods Corp., covered the subject of arc welding electrodes. Using slides, Mr. Clemens discussed the properties and applications of mild steel, low-hydrogen and low-alloy electrodes. After the talk a question period was led by William McClellan who acted as chairman of this session.

The final talk of the meeting was given by A. N. Kugler, AWS, of the Air Reduction Sales Co. Mr. Kugler's talk was titled "Brazing and Braze Welding." This paper explained the difference between true brazing and the somewhat related operation of braze welding. Slides were used to illustrate typical operations in both fields. With the conclusion of Mr. Kugler's talk the conference was adjourned by Glenn Hickok, Chairman of the Western Michigan Section.

Submerged Arc Welding

Houston, Tex.—At the regular monthly meeting of the *Houston* Section, held on February 24th, G. C. Ransone, Linde Air Products Co., Kansas City, gave a most interesting and enlightening talk on "General Methods of Submerged Arc Welding." His talk covered all phases of Submerged Arc Welding and slides were used extensively as a descriptive aid to assist the audience in understanding many of the technical points.

One hundred and forty members and guests attended the dinner meeting.



Officers Sabine Division of Houston Section: Left to right—Paul Reitz, Walter Riley, Geo. Trotter, Jr., Joe Hoffman, Glenn L. Martin, S. W. Scurlock, Don S. Reichle. E. F. Cooke, Director, not present

Soft Soldering

Indianapolis, Ind.—Wyman Wills, in charge of Sales of Extruded Metals for the Federated Metals Division of American Smelting and Refining Co., Whiting, Ind., gave a very good presentation of "Soft Soldering" at the March 26th meeting of the *Indiana* Section.

Tin-lead solders and low-temperature melting alloys were covered very thoroughly as to their metallurgical and physical properties in many applications to industry. A very interesting question-and-answer session followed.

Forty-four members and guests enjoyed this meeting which started with a 6:30 chicken dinner at Buckley's Restaurant and was followed by a color sound movie by Canadian Pacific R. R. which was beautiful and interesting.

Silver Alloy Brazing

Kansas City, Mo.—The *Kansas City* Section held their March 9th dinner meeting in Fred Harvey's Pine Room. Chairman A. G. Hedstrom held a brief business meeting prior to the technical meeting.

Program Chairman Frank Singleton introduced the speaker, Robert Tilley. Mr. Tilley, Field Sales Engineer for Handy and Harman, spoke on the subject "Silver Alloy Brazing of Dissimilar Metals." Mr. Tilley began his talk by giving some interesting history of brazing. He went on to discuss some of the corrosion and expansion problems that are encountered during brazing. He then discussed in detail definite problems encountered in brazing certain combinations of metals.

Mr. Tilley followed his talk with a film entitled "Production Silver Brazing."

Aluminum Alloy Castings

Los Angeles, Calif.—The Aircraft and Rocketry Panel of the *Los Angeles* Section held its April meeting on the first at Swally's Key Club. The subject of the Panel, "The Welding of 356 Aluminum Alloy Castings," was presented by Walter S. Tenner, AWS, Director of Metal Process Section, U. S. Naval Ordnance Station, Pasadena.

Mr. Tenner's paper on the subject included material and joint preparation, tools, equipment and welding techniques and special appli ations.

The investigation of inert-gas-shielded tungsten arc welding of aluminum castings was deemed necessary because of inconclusive data on the weld physical properties in 356 aluminum castings.

Weld specimens were prepared in the Ordnance Casting Laboratory. The nominal composition of the castings made at the laboratory was 7% Si, 3% Mg and balance Al.

The test plates were sand cast in thicknesses of 1/4, 1/2 and 1 in. The gates were machined off and their base areas used as part of the weld specimens.

The 1/4-in. plates were square butt prepared for welding, the 1/2-in. plates were single V and 1-in. plates were double V prepared. Convenient root openings and root faces were also used.

The test plates were inert-arc welded with an AC-HF Welder.

Filler wire employed consisted of 43S (5% Si), 718 (11% Si) and 356 (7% Si, 0.3% Mg) extruded wire.

From tensile and pressure test results, Mr. Tenner arrived at the following conclusions:

1. Magnesium is required in the weld for subsequent heat treat response to T6 condition.

2. The 1/4-in. plates, square-butt-groove prepared, can be welded with 43S and 718 wire and the subsequent weld will respond to heat treat. A 100% joint efficiency was obtained in the weld using this procedure.

3. To obtain 100% joint efficiency in heavier plates that must be V-groove prepared, the 356 extruded aluminum alloy wire should be used.

4. To obtain 100% joint efficiency, all weldments must be heat treated to the T6 condition.

Structural Steel Fabrication

Milwaukee, Wis.—The March meeting of the *Milwaukee* Section was held in the Rathskeller of the Ambassador Hotel on March 26th with 94 in attendance for the dinner. This was Past-Chairmen's Night, honoring 18 past-chairmen down through the years from 1935 when the Section was

installed. It was a big night when many old friends and acquaintances met again.

After dinner, Roger Bessey, a Milwaukee attorney, spoke on the topic "Facts Behind the Judicial Poll." The poll is sponsored by the Bar Association each election year to determine which candidates for judge are best qualified for the position in the opinion of the lawyers. It is a secret ballot and the results are published in the newspapers prior to the election. The talk was timely since elections take place April 6th.

The technical speaker was Erwin C. Brekelbaum, AWS, Director of Methods for the Thew Shovel Co., Lorain, Ohio. "Brek" was a past-chairman of the Milwaukee Section in 1943 and was very popular throughout the area in the welding field since he was Executive Chief Engineer and Vice-President of the Harnischfeger Corp. for several years. He was also very active locally in welding, having been chairman of the Industrial Advisory Committee of Welding and Engineering at the Milwaukee School of Engineering. The talk, in general, covered new trends in materials and methods used in structural steel welding. He brought out, in a very interesting manner, the importance of proper coordination of engineering, planning, manufacturing and inspection in the control and economical manufacture of structural steel fabrication indicating that machine shop standards should be revised for welded structures. He delved into the very controversial subject of cast-versus-fabricated parts, pointing out there is a definite need for both in industry today.

Automation

Milwaukee, Wis.—The April meeting of the *Milwaukee* Section was held at the Ambassador Hotel on April 23rd with approximately 100 in attendance. This was Past-Secretaries' Night honoring Gil Meyer, C. Hart, R. P. Walbridge and F. J. Harencki.

After dinner, George Sprecher, Assistant Director, Conservation Department, State of Wisconsin, gave a very interesting coffee talk on the topic "What Conservation Means to You," covering soil erosion, reforestation, fish and game control and protection.

In the business meeting following, the Nominating Committee presented the following slate of officers and directors for 1954–55.

Chairman—Donald E. Wilson
Vice-Chairman—Joseph H. Stevens
Secretary-Treasurer—Francis J. Harencki
Directors—Werner J. Gallo, John J. Linnehan, Anton L. Schaeffler, Clarence Dorau

The technical speaker was Charles F. Hautau, Chief Engineer and Secretary-Treasurer of the Hautau Engineering Co., of Detroit, Mich., who spoke on the very opportune subject "Automation." Mr. Hautau, after graduation as a mechanical engineer from the university of Detroit, joined Fisher Body Central Machine Division as a designer and later became a checker of stamping equipment, dies, fixtures and automatic unloaders. In 1941, he joined the Manufacturing Engineering Service Co. as Chief Engineer and later became Chief Engineer of the Anderson Aircraft Co. until he organized his present company in 1946 to design and build special machinery, automatic equipment and complete factory manufacturing lines. Mr. Hautau, who is an authority on automation, gave an excellent presentation illustrated with slides and movies. He likened automation to a symphony orchestra where all of the individual instruments blend their operations to produce a finished product with the least amount of equipment, personnel and plant area at great reductions in over-all costs. In many plants, products and methods are being obsoleted daily through the use of automation.

Oxy-Acetylene Cutting

Newark, N. J.—Some 90 members and guests enjoyed the dinner and meeting of the *New Jersey* Section at the Essex House in Newark on Tuesday, March 16th. Speaker of the evening was R. F. Helmkamp, AWS, one of the foremost authorities on the subject of oxy-acetylene cutting in this country. Mr. Helmkamp has been on the staff of Air Reduction Co. since 1919 and has been identified with all of their gas-cutting machine developments.

In his talk the speaker delineated clearly the difference in performance and use of manual, magnetic and electronic tracing for the reproduction of cutting. He showed the various steps in the development of the modern machine and the special utility of each.

Metal Joining

Newark, N. J.—On Tuesday, April 20th, *New Jersey* Section heard a well-rounded talk on some phases of "Metal Joining" which have slipped into the background.

The speaker, E. F. Davis, AWS, Manufacturing Consultant of the Westinghouse Electric Corp., has a 25-year background on the subject of his talk, including 12 years in the Westinghouse Metals Joining Laboratory, several years in charge of staff activities in that field prior to his attainment of his present post.

In addition to the better known welding techniques, Mr. Davis covered at some length the fields of brazing and silver soldering. Using slides to illustrate his points, he outlined the properties of current brazing alloys, the preparation of joints including knurling and the special precautions required to get results on steel, aluminum, stainless, copper and aluminum bronze. He also covered the heating media—torch, inert arc, high-frequency induction and the resistance sources.

The social hour after the meeting was enjoyed by everyone as usual.

Welding Clinic and Forum

New York, N. Y.—The *New York* Section sponsored a Welding Clinic and Forum held at the New York Trade School, New York City, on Mar. 26 and 27, 1954. Demonstrations of recent developments in welding and exhibits of the latest welding equipment were presented by the manufacturers and suppliers of welding equipment and supplies. Among many demonstrations presented were Inert-Gas-Shielded Arc Welding, Gas Welding and Brazing, Phos-copper and Silver Alloy Brazing and Resistance Welding with Portable Machines. The latest industrial motion pictures on welding and cutting were also shown. The Clinic and Forum was well received with a registration of over 600 and a total attendance of over 800 members and friends for the two dates.

Inert Arc Welding

New York, N. Y.—"Inert-Gas-Shielded Arc Characteristics in Heliarc Welding" and "New Applications of the Inert-Gas Consumable-Electrode Process" were the titles of two papers presented to the *New York* Section on Apr. 13, 1954. J. R. Craig, Eastern Region Engineer, Linde Air Products Co., presented the former and H. E. Cook, Process Development Engineer, Air Reduction Sales Co., the latter. The principles of inert-gas metal-arc welding were reviewed pointing out the particular aspects which give the process its advantages over other welding methods. A number of actual applications of the process in industry were discussed with the aid of slides. Included were steel and stainless steel fabrication, an automatic pipe welding machine, and a discussion of the fusion welding of titanium and zirconium.

The meeting was held at Schwartz's Restaurant, 54 Broad St., New York City, where dinner was served prior to the technical session.

Offshore Drilling

Pascagoula, Miss.—The April 7th dinner meeting of the *Pascagoula* Section was held at Ingalls Shipyard Cafe. Hoyt Taylor, Drilling Engineer, Gulf Coast Division, Kerr-McGee Oil Industries, Inc., Oklahoma City, Okla., spoke on the subject "Offshore Drilling."

Through the courtesy of the Alaska

Steamship Co., a sound color film entitled "Alaska" was shown.

Inert Arc Welding

Philadelphia, Pa.—At the March 15th meeting of the *Philadelphia* Section, held at the Engineers Club, Roger Tuthill, AWS, of General Electric Co. presented a lecture on a new style of welding generator for use in the consumable inert-gas metal-arc welding processes. By designing the D-C Welding generator to give a rising voltampere curve, he claims to achieve greater arc stability and less danger of short-circuiting to the work or "burn back" damage to the gun. The welding process using this new style equipment has been designated the "Fillerarc" process.

During his lecture and in the lively discussion which followed, Mr. Tuthill mentioned the use of the process to weld aluminum, stainless steels, titanium and many other metals. Its application for welding carbon steels, he believes, depends upon whether or not the relatively high cost of the inert gas can be offset by the other advantages of the process.

Bronze Welding

Philadelphia, Pa.—A leading authority on bronze welding, F. Emery Garriott, AWS, of Ampco Metal, Inc., presented to the *Philadelphia* Section at its April meeting, held on the 19th, an outstanding lecture on jobs one can do with bronze electrodes. He showed how the properties of copper base alloys are admirably suited to the joining of certain dissimilar materials, to the welding of similar copper base alloys, and to the surfacing of steels for corrosion, erosion or abrasion resistance. All of the known arc-welding processes seem to be applicable to most of the common bronze welding alloys. A lively discussion followed at which time Mr. Garriott answered specific questions relating to actual applications. A feature of the dinner program was Prof. Francis Davis who spoke on the control of weather by the methods of seeding clouds to make rain.

The following officers were elected for the 1954–55 season.

Chairman—R. David Thomas, Jr., Arcos Corp.
Vice-Chairman—E. E. Goehringer, Lincoln Electric Co.
Secretary—A. M. Garcia, Morris Wheeler & Co.
Treasurer—L. D. T. Berg, Arcway Equipment Co.
Executive Board Members (for three-year term)—A. B. Gordon, R. S. Phair, Arnold Rose
Executive Board Members (for two-year term)—Robert Benwell, Fred Judelsohn, James Thistle

Robert Irving of Morris, Wheeler & Co., Inc., was appointed Recording Secretary to replace Henry Young, K. Wm. Ostrom & Co., who, because of other pressing activities, relinquished these duties after serving faithfully for over three years.

Safety in Welding

Pittsburgh, Pa.—The regular monthly dinner meeting of the *Pittsburgh* Section was held on March 17th in the auditorium of the Mellon Institute of Industrial Research. Dinner at the Hotel Webster Hall preceded the meeting.

The speaker at the meeting was S. A. Greenberg, Technical Secretary, AWS, who gave an extemporaneous talk on the subject "Safety in Welding Operations." Mr. Greenberg contends that if welding operations are undertaken with common sense, then welding is a safe operation and the operator is safer when welding than when driving his car. He pointed out, however, that it is an essential step in applying common sense to place in one person the responsibility for safety for the plant.

Fusion Welding Developments

Portland, Ore.—In keeping with its practice for the past few years, the *Portland* Section met on April 16th with the Oregon Chapter of the American Society for Metals at the Congress Hotel in Portland.

A refreshment and social period preceded the dinner at 7:00 which was followed by the technical meeting at 8:00. The speaker of the evening was C. B. Robinson, AWS, of Air Reduction Pacific, San Francisco. His talk on "Recent Developments and Applications in Fusion Welding" was accompanied by a sound picture and also a silent film, both of which he worked into his talk. This was presented in a fine manner and held the interest of all who attended.

Codes and Electrodes

Rochester, N. Y.—The regular monthly meeting of the *Rochester* Section was held on the 15th of March at the Rochesters Turners, with an attendance of 46 at dinner and meeting. Dinner Speaker was A. J. Palmer, Senior Income Tax Examiner for the State of New York, who spoke on "New Facts About Your New York State Tax." Speakers for the Technical Session were Nelson Martin, Welding Specialist, Foster Wheeler Corp., who spoke on "Welding Procedures in Accordance with Various Codes," and Neal Lawton, District Representative, Lincoln Electric Co., whose topic was "Applications of Powdered Metal Electrodes." These talks were followed by a lengthy question-and-answer period.

Mild Steel Tubing

Saginaw, Mich.—The annual meeting of the *Saginaw Valley* Section was held Apr. 8, 1954, at the High Life Inn in Saginaw, Mich. The following officers were elected for the 1954-55 season:

Chairman—W. E. Moehring
Vice-Chairman—I. S. Makulinski
Secretary—W. E. Woollard
Treasurer—J. Stanilus

After the presentation of the new officers, Mr. Blackwood was congratulated on the very fine job that he did as chairman for the 1953–54 season and he was presented with the AWS Past-Chairman Pin.

After the business transactions of the meeting, Mr. Blackwood presented Mr. Thomas, Electrical Engineer from the McKay Machinery Co., as the main speaker of the evening. His subject, "Electric Resistance Welding of Mild Steel Tubing" was heard by 80 members and guests.

Mr. Thomas, with slide illustrations, showed and discussed the early patented designs for electrical circuits of resistance welding, starting from simple circuits for spot welding to the rotary transformer type circuits for tube mill welding. Data concerning the relationship between power, speed and tube wall thickness, and voltage, speed and tube wall thickness was illustrated and discussed. Mr. Thomas pointed out and discussed the four important steps in tube mill welding which are (1) forming, (2) welding, (3) straightening and (4) cut-off. Welding speeds as high as 360 fpm are attainable but at these high speeds the current frequency has to be increased in order to form at least 8–10 spots per inch.

After the presentation, a discussion period followed and Mr. Thomas answered all questions from the audience. Following this, a movie illustrating "Tube Mills in Action" was shown, explaining the four important parts of the mill: the forming dies, welding head, straightening dies and cut-off, as in operation on a regular production run. The movie ended Mr. Thomas' excellent presentation and it was well received by the members and guests, some of whom lingered afterward to ask more questions.

Social Meeting

Salt Lake City, Utah.—A nontechnical meeting to which the wives of the members of the *Salt Lake City* Section were invited was held on March 12th at the Elks Club. Sixty-nine members and guests were present and enjoyed seeing slides of the Four Corners Area of Southern Utah as shown by Roy Potts, AWS, of the Industrial Supply Co.

Hard Facing

Seattle, Wash.—Fifty members and

guests of the *Puget Sound* Section met at dinner on April 8th at the Engineers Club and heard an excellent coffee talk by Capt. C. Douglas of the General Section, U. S. Army, on the "German Civilians of Today."

An excellent semitechnical talk on the "Story of Hard Facing" was given at the meeting by Raymond A. Larson of the Stoody Co.

Tour

South Bend, Ind.—The *Michiana* Section and the *Anthony Wayne* Section jointly took part in a conducted tour of portions of the Bendix Products Division of Bendix Aviation Corp. in South Bend on April 15th. After dinner, served with the compliments of the Bendix Corp. in the Bendix Cafeteria, some 130 members and guests walked over one and a half miles while observing various types of welding and other operations. Of special interest were a "brazing table," actually a silver-soldering operation wherein the parts are loaded on a large, rotating table, and in the course of one rotation are soldered by means of gas-fired torches; a double-end flash-butt welder making automatic transmission bands; an inert-arc welding setupon steels, welding SAE 1137 to 1010 for power steering units; a flash-butt welder making aircraft quality welds in steel subsequently heat treated to 220,000 psi; and arc welding on AMS6324 and kindred steels for aircraft landing gear. Thanks were extended to Bendix for a very enjoyable and instructive evening.

Weld Inspection

Springfield, Ill.—The *Sangamon Valley* Section held its April Dinner Meeting on the 13th. Thomas Stevens, of the Mid-West District of the Magnaflux Corp., presented a technical discussion on the subject, "Nondestructive Weld Inspection," which was illustrated with slides.

Bronze-Filler Metals

Syracuse, N. Y.—The *Syracuse* Section met on April 14th and approximately 70 members and guests attended. Special guest at the meeting was National Secretary J. G. Magrath, who spoke on the various activities of the SOCIETY.

Technical speaker was F. E. Garriott, AWS, Manager of the Weld Rod Division, Ampco Metal, Inc., Milwaukee, Wis. Mr. Garriott spoke on the jobs you can do with bronze electrodes and filler rods. He pointed out that because bronze electrodes and filler rods are very versatile, they can be used for both joining and overlay. For selection of proper electrode or filler rod for specific application, four steps must be followed: (1) Use wide grooves—60–90-deg over-all V except light gage. (2) Preheat and interpass temperatures—heavy sections. (3) Current recommendations. (4) Overlay iron-base metals such as SAE 1040.

Mr. Garriott also discussed various types of Phosphor bronze electrodes and filler rods and aluminum-bronze electrodes and filler rods.

In conclusion, he stated that under present-day conditions of steadily increasing production, maintenance and replacement costs and an attempt to lower selling prices to meet competition, drastic economies can be made in many ways through the use of bronze electrodes and filler rods.

Welding Procedures

Tucson, Ariz.—The *Tucson* Section held its regular monthly dinner meeting on April 20th at the Municipal Golf Course Clubhouse. Guest speaker was Victor H. Lyons, AWS, District Sales Manager for Eutectic Welding Alloys Corp, Tulsa, Okla. Mr. Lyon showed a 16-mm. color film entitled "New Welding Procedures," after which he discussed new alloys and procedures for welding. Mr. Lyon held such a very interesting question-and-answer session after the formal talk that the members were requested by the Clubhouse to leave because it was past closing time.

Plant Visit

Wellsville, N. Y.—The *Olean-Bradford* Section met for a dinner meeting at the Elks Club in Wellsville on April 19th.

Through the courtesy of the Air Preheater Corp., the group was conducted through their new plant, which proved a very interesting visit. Members of the corporation acted as guides for the different groups.

Rectifier Welder

Worcester, Mass.—The *Worcester* Section held its regular monthly dinner meeting on April 5th at the Tower House.

G. K. Willecke, AWS, of the Miller Electric Manufacturing Co., spoke on a relatively new and not too well known subject—"The Rectifier Type D-C Welder." Mr. Willecke is a co-designer of the Miller Rectifier Welder and has served as Chairman of an industry wide technical subcommittee to study and make recommendations on the problem of high-frequency stabilized welders. Mr. Willecke presented a "down-to-earth" discussion of the basic principles of the rectifier-type welder, couched in language that is readily understood by welding engineers and operators.

---

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington 25, D. C.

2,673,471—CHAIN SPROCKET WITH SELECTIVE WELDED HUB—Theodore S. Kline and George K. Robers, Sacramento, Calif.

This patent is on a specialized type of a welded hub construction.

2,673,915—TWIN ARC WELDING SYSTEM—Emil F. Steinert, Williamsville, Harry J. Bichsel, East Aurora, and Martin Rebuffoni, Williamsville, N. Y., assignees to Westinghouse Electric, Pittsburgh.

This patent covers the combination in a twin arc welding system of a pair of electrodes disposed in arcing relationship with a workpiece and moved along the workpiece in a predetermined sequential relationship in the direction of the welded

seam. A pair of transformers having primary windings supplied from two different pairs of the phase conductors of a three phase source of alternating current and secondary windings each having a pair of terminals are also provided in the combination. One of the terminals of each secondary is disposed to be connected to the workpiece and the other terminals are disposed to be connected each to a different one of the electrodes.

2,673,916—Welding Process and Apparatus—Amel R. Meyer, Griffith, Ind., assignor to Graver Tank & Mfg. Co., Inc., East Chicago, Ind., a corporation of Delaware.

This relates to a welding process for use on a workpiece surface oriented in other than the flat downhand position. The process comprises the steps of traversing the surface with a flux submerged arc and supporting the resulting melt by pressing a resiliently compressible, heat-insulating body against the exposed face of the melt to partly compress the body.

2,674,217—Welding Machine with Backup Means—Morris S. Rosenblatt and Leo R. Davis, Salt Lake City, Utah, assignors to the Eimco Corp., Salt Lake City, Utah, a corporation of Utah.

The apparatus patented by such patent is provided for backing up a seam between members to be welded and comprises a vertical hollow cylindrical member supported against the under side of the seam to be welded and a transverse member movably positioned within the cylindrical member and defining therewith a chamber at the upper end of the cylindrical member for granular refractory material. A flexible sleeve of noncombustible fabric is attached to and projects beyond the upper end of the cylindrical member and means urge the transverse member in an upward direction for pressing the refractory material against the seam.

2,674,523—Process and Composition for Treatment of Magnesium Prior to Spot Welding—Louis McDonald, Altadena, and Alfred E. Hawley, Long Beach, Calif., assignors to Kelite Products, Inc., Los Angeles, Calif., a corporation of California.

In this patent, a process for cleaning magnesium prior to spot welding is disclosed and the patent primarily covers the particular chemical composition of the cleaning material used.

2,674,679—Automatic Assembling and Welding Apparatus—Hershey Roy Graybill, Manheim, Pa., assignor to Radio Corporation of America, a corporation of Delaware.

Graybill's patent is on an assembling and welding apparatus comprising a loading means, guiding means in registry with the loading means adjacent thereto, welding means in the guiding means and movable means movable through the loading means and guiding means. Such movable means are adapted to move workpieces to be welded from the loading means to the welding means. The welding means move in a path including a portion of the welding means so as to stop a welding operation.

2,674,966—Welding Clamp—Melvin P. Morris, Okmulgee, Okla.

Morris' patent relates to a self-supporting fluid pressure operated welding clamp for holding two pipe elements in end-to-end relation.

2,675,453—Apparatus for Manufacture of Welded Terminal Resistors—Fredrick Isaac Ellin, Chicago, Ill., assignor to David T. Siegel, Glencoe, Ill.

This patent relates to mechanism for manufacturing articles such as resistors and the mechanism comprises a base, an arm pivotally mounted on the base, rotatable means carried by the arm, and means on the arm for supporting the projection of a metallic encompassing band on a resistor. Other means on the base support a terminal to be welded onto the projection and means are provided for rotating the rotatable means on the arm so that further means can operate the projection-supporting means to support a projection thereon. After a predetermined degree of rotation of the rotatable means, another member pivots the arm to bring the projection and terminal into contact so that the terminal can be welded to the projection.

2,675,454—Welding or Soldering Apparatus—Samual W. Warner, Newark, N. J.

Warner's patent relates to a portable hand-operated welding apparatus. The apparatus includes a handle, a pair of spaced supporting and guide members on the handle, and a pair of electrode carriers independently slidably mounted in parallel association on the members. Spring means are associated with the members and the carriers to exert a constant bias on the carriers tending to move them in one direction while other means are provided to preclude rotational movement of the carriers.

2,676,230—Electrical Control Apparatus—John J. Czaja, Detroit, Mich. assignor to Weltronic Corp., Detroit, Mich., a corporation of Michigan.

This patent is on a control circuit for a welding machine that requires a flow of coolant during its operation. The control circuit includes a sequencing network for controlling the operation of the machine, a coolant flow control means and means for initiating operation of the network. Other means are provided for actuating the coolant control means to a condition to permit flow of coolant to the machine. Time delay means are present and are actuated as a consequence of the actuation of the final sequencing step of the network for holding the coolant control means in flow-permitting condition for a desired time interval, subsequent to completion of the sequencing operation of the network.

2,676,231—Electrode Holder for Arc Welding—Ian Jack Pickering, Birmingham, England, assignor to the General Electric Co. Ltd., London, England.

Pickering's patent is on a welding electrode holder for use with two-phase welding current systems. The holder includes two current-carrying arms flanking one another, connections for supplying electric current to the arms, and solid electrical insulation between the arms toward one end thereof and air insulation between the arms toward and at the other end. A lever having a surface adapted to engage the bared end of one of the electrodes of the double electrode is provided and a surface is adapted to engage the bared end of the other electrode. A fulcrum is provided for the lever on the other arm and resilient means urge the surfaces toward each other to engage and grip the bared ends of the electrodes of the double electrode between them.

JOIN THE AMERICAN WELDING SOCIETY . . . . NOW!

Now...
The Newest
In Electrode
Protection...

EASY TO OPEN

Just strip the tape and lift the metal lid. No cutting or "breaking open."

EASY TO CLOSE

Simply push the lid on again. Its recessed rim provides a tight closure against moisture.

the new Arcos

ELECTROPAK

gives you all the packaging advantages you want

The unique construction of this packaging method was first developed for shipping wartime materials. From the arctic to the equator it provides excellent protection against weather damage and rough handling. Its *new* application by Arcos makes it the *most modern protective package yet devised* for electrodes.

PREVENTS MOISTURE PICKUP

Between the outer and inside walls is sandwiched a sheet of aluminum foil. This, plus an outer aluminum foil wrap and alternating layers of ammunition board and asphalt provides an excellent vapor barrier seal.

PREVENTS CHIPPED COATINGS

In addition to its strength, ammunition board is also resilient, thus providing a cushion to prevent chipping.

ARCOS CORPORATION

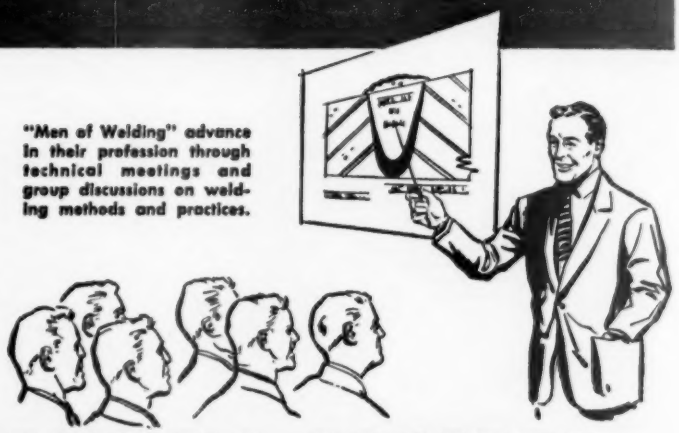
1500 South 50th Street, Philadelphia 43, Pa.

INDEX TO ADVERTISERS

Acme Manufacturing Co. 594
Air Reduction ..... Outside back cover
All-State Welding Alloys Co., Inc. 580
American Cancer Society 604
American Chain and Cable 601
American Welding Society 626
Ampco Metal, Inc. 595
Anaconda ..... Inside back cover
Anti-Borax Compound Co. 608
Arcair Company 600
Arcos Corporation 625
Armour Research Foundation 609
Aronson Machine Co. 588
Dockson Corporation 586, 587
Eastman Kodak 603
Erico Products, Inc. 583
General Electric 596, 597
Hays Manufacturing Company 607
Haynes Stellite Company, a Division of Union Carbide and Carbon Corp. 585
Hobart Brothers Company 525
The International Nickel Company, Inc. 530
The Lincoln Electric Company 613
Linde Air Products Company, a Division of Union Carbide and Carbon Corp. 528
P. R. Mallory & Co., Inc. 527
Metal & Thermit Corporation 526
National Carbide Company 606
National Cylinder Gas Company 611
National Welding Equipment Co. 581
Page Steel and Wire Division 601
Sciaky Bros. 605
A. O. Smith 589–592
Square D Company 619
Stahl Equipment Company 608
Stulz-Sickles Co. 582
Sylvania Electric Products, Inc. 599
Tweco Products Company 615
Union Carbide and Carbon Corporation
Haynes Stellite Company 585
Linde Air Products Company 528
Victor Equipment Company ..... Inside front cover
Westinghouse Electric Corporation 608

A. W. S. Builds "MEN OF WELDING"

There are 66 active local sections of A.W.S. covering the entire United States. The 9,683 members of A.W.S. hold monthly technical meetings and plant visitations where they observe practical solutions to typical welding problems and study new welding methods. They receive accurate information on welding design, fabrication and maintenance through discussions with the best welding minds in the nation and authoritative printed reports.



"Men of Welding" advance in their profession through technical meetings and group discussions on welding methods and practices.

AMERICAN WELDING SOCIETY

A powerful force in welding progress since 1919

33 WEST 39TH STREET • NEW YORK 18, NEW YORK

YOUR COMPANY

can participate through a sustaining or supporting membership. Get the facts about A.W.S.

AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, New York

6/54

Please send me more information on the personal and company advantages of membership in A.W.S.

NAME _____

FIRM _____ ADDRESS _____

TITLE _____ CITY _____ ZONE _____ STATE _____

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers, Society of Naval Architect and Marine Engineers, American Society for Metals and American Society for Testing Materials

Supplement to the Welding Journal, June 1954

Nucleation and Growth of Graphite in Steel

A condensed statement of the problem of graphitization of steel and measurements on the nucleation and growth of graphite

by Floyd Brown

MEASUREMENTS on the nucleation and growth of graphite in steel are reported here in context with an abbreviated restatement of the problem of graphitization in steel, a subject which has been treated in at least forty original papers in the major journals since attention to the phenomenon was increased so abruptly by its association with a weldment failure in 1943. This same phenomenon of subcritical graphitization of cementite has received much attention for many years in the cast iron field, and since in spite of the difference in carbon and silicon levels the same principles are involved as in steel, some of the ideas developed in that field will be drawn upon throughout.

NUCLEATION OF GRAPHITE

Graphite in steel forms as aggregate-type* nodules which may be either randomly distributed (Fig. 1) or attached to each other forming a chain along the grain boundary (Fig. 2; for a more extreme example see Reference 1). The site of nucleation of the graphite has not been established in steels, but indirect evidence leads to the conclusion that in cast iron it is at the ferrite-cementite interface.[†, 3] This conclusion was reached much earlier[4] in accounting for the rapid graphitization of quenched irons on the basis of easier nucleation at the sharply rounded ferrite-cementite

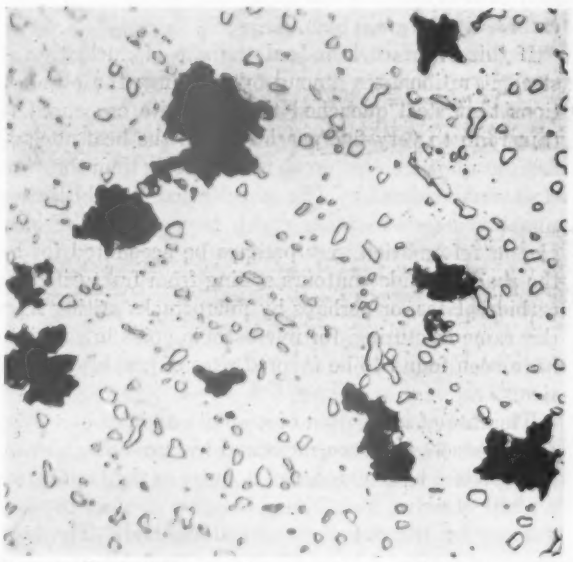


Fig. 1 Essentially random graphite nodules in steel quenched and held 69 hr at 700° C. × 1000

interface of fine carbides derived from tempered martensite. It is, of course, also true that the carbon content of the ferrite is slightly higher in equilibrium with sharply curved carbides than with gently curved ones, leading to slightly larger diffusion potentials (Δ in Fig. 6). Energy considerations favor this interface site, and even more if it is met by a ferrite grain bound-

Floyd Brown is with the Department of Engineering Research, North Carolina State College, Raleigh, N. C.

* The crystallography and metallography of graphite are discussed in Reference 2.

† One finds, for example, that specimens of white cast iron heated slowly through a subcritical range or held for an hour or so at 400° C form many more graphite nodules (during the subsequent malleabilizing anneal) than specimens heated rapidly or held isothermally at another temperature; if, however, this slow heating or isothermal holding is performed not in an inert atmosphere but in a hydrogen-bearing one (which inhibits graphitization but not spheroidization of the carbides), the extra graphite seen to form in inert atmospheres does not form. From this the conclusion is drawn that the sharply rounded carbides favor graphitization more than the smoothly rounded, spheroidized ones, and that the site of the nucleation is at the surface of the carbide, i.e., at the ferrite-cementite interface.

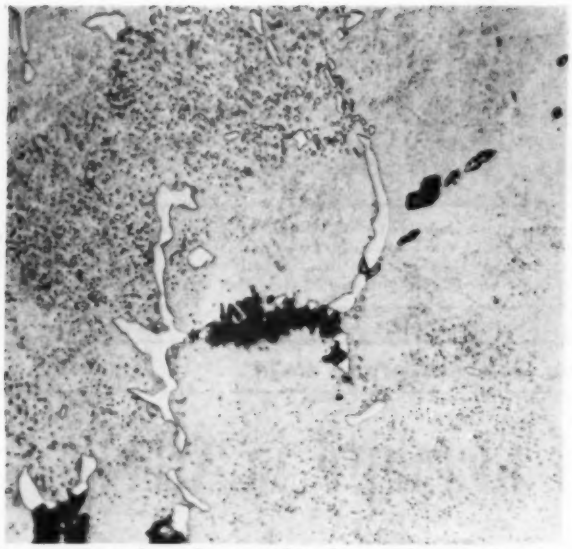


Fig. 2 Grain boundary graphite formed by transforming austenite 16 hr at 5° C below critical. (Remainder of structure is martensite, grain boundary carbides and fine general carbides.) × 1000

ary, so that the most favored sites would be at small carbides in the grain boundaries.

If this interface is indeed the site of nucleation in steel, it rationalizes among other things the observations that steel quenched to martensite or caused to transform to very fine pearlite, as in the heat-affected zone, graphitizes very much more rapidly than the same steel spheroidized.* The accelerated graphitization sometimes seen in zones which have undergone local plastic deformation may perhaps be accounted for by the sharp carbide contours arising from fracturing the carbide plates, or perhaps by microcracks arising from this same fracturing, for microscopic voids in cast iron have been found to be favored sites of graphite formation.

The rate of nucleation of graphite nodules in a plain carbon steel† has been measured by measuring the diameters of a large number of nodules as they appear on a plane of polish and finding the true number per unit volume by the Scheil statistical method. The steel was austenitized 1 hr at 825°, quenched out, tempered 15 min at 700°, and independent specimens than graphitized at various temperatures in dried helium. The total number of nodules at various times is plotted in Fig. 3. It appears that there is a maximum in the rate of nucleation at about 640°, and that there may have been at two temperatures the same sort of coalescence of nodules sometimes seen in malleable iron[5] and also reported for steel.[6]

As in many nucleation-and-growth reactions in physical metallurgy, the *rate* of nucleation increases with time, starting out at a rate so low that there is in effect

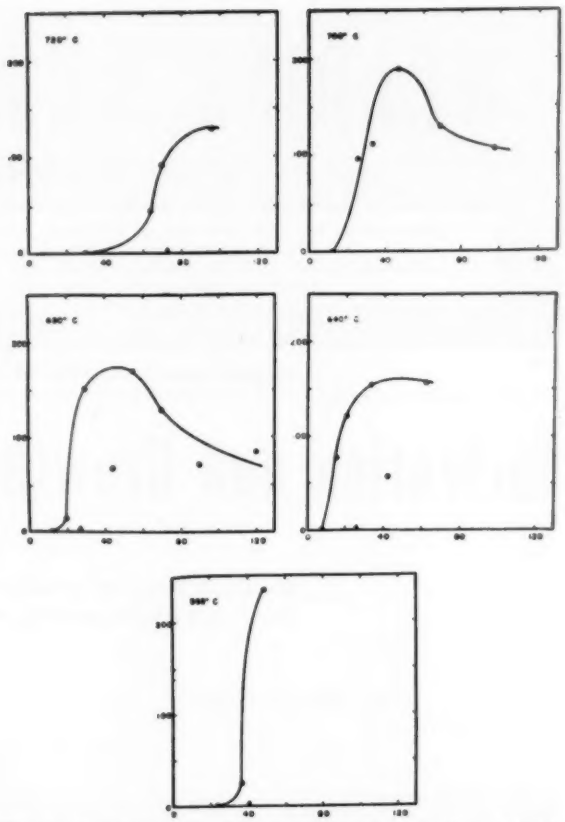


Fig. 3 Number of graphite nodules as a function of holding time at various subcritical temperatures. Time in hours is plotted as abscissa, total number of nodules per cubic inch (at × 1000) as ordinate. Carets mark time required for an arbitrary (28.5%) amount of reaction

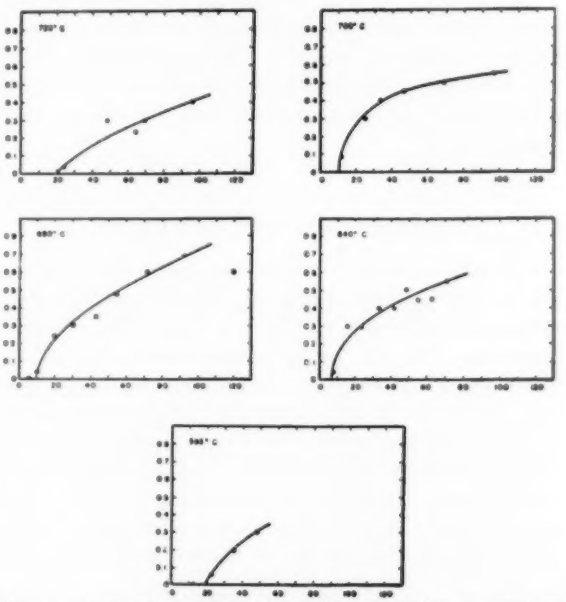


Fig. 4 Rate of growth of graphite nodules at various temperatures as indicated. Time in hours is plotted as abscissa, nodule diameter in thousandths of an inch as ordinate

* It might be suggested in passing that if one were actually practicing spheroidizing or tempering to mitigate graphitization, it would be well to conduct this heat treatment in ammonia or methane, either of which will ensure that graphite is not nucleated during this treatment.

† 1.00% C, 0.44 Mn, 0.15 P, 0.031 S, 0.23 Si. This same steel was used for the growth rate measurements and the *t-t-t* curve reported here and for the photomicrographs of Figs. 1 and 2.

an "incubation period." There is no evidence or apparent necessity for attributing to this "incubation period" any peculiar reaction which does not continue throughout the course of the graphitization.

The conditions leading to pronounced grain boundary nucleation as opposed to general nucleation do not appear to be well defined, although the relative effects of these two distributions would suggest to the metallographer vastly different mechanical properties.

GROWTH

The rate of growth of the individual graphite nodule has been measured by measuring the size of the largest nodules in specimens graphitized at various times. Growth curves so derived for five temperatures (Fig. 4) are quasi-parabolic, and one might be tempted to infer that this indicates a diffusion-controlled process. This is not the case. Although diffusion is patently involved, it is not controlling, and the growth curve bends (1) because the number of nodules competing for carbon increased during the reaction and (2) because the supply of rapidly dissolving small carbides is exhausted leaving only the larger carbides. The observations that a few carbides remain in the vicinity of the graphite while those more remote begin to dissolve, but that carbides nearer the graphite disappear in general somewhat sooner than remoter carbides similarly sized, combine to indicate clearly that both the rate of diffusion of the carbon from carbide to graphite and the rate of carbide solution are involved in controlling the rate of growth of the individual nodule.

TEMPERATURE DEPENDENCE OF REACTION RATE

The percentage of carbon as graphite in the various specimens of the steel used above was measured metallographically and the curve of Fig. 5 drawn to summarize these data. Figure 5 shows a maximum in reaction rate, as has been previously reported by many observers. These intermediate maxima in nucleation rate, growth rate and reaction rate are readily accounted for by the competition between rate of dissolution of carbides and diffusion of carbon on the one hand and rate of spheroidization on the other. Both of these increase with increasing temperature, but at low temperatures the low rates of dissolution and diffusion control while at high temperatures the rate of spheroidization predominates, giving in both instances a lower rate of graphitization than at an intermediate temperature. There does not seem to be at the present time either need or evidence for introducing any other special transformation or reaction to account for this maximum rate of graphitization.

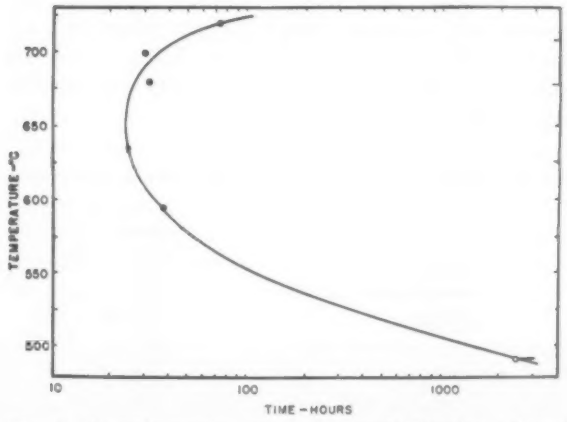


Fig. 5 Transformation curve for graphitization of steel (time for 28.5% reaction)

ALLOYING ELEMENTS

Graphitization behavior is apt to be highly sensitive to alloying elements, most of which stabilize the carbide phase against graphitization but a few of which (in cast iron, at least) appear to be inherent graphitization promoters; many of the minor elements present in all commercial steels which have negligible effects on hardenability or mechanical properties may affect profoundly the graphitization behavior. This has increased the task of disentangling the effects of the various elements, a task further enormously complicated by interaction between several elements. Manganese and sulfur are both strong carbide stabilizers, for example, but they interact with one another, so that if one adds manganese to a sulfur-bearing alloy the effect is first to neutralize sulfur and accelerate graphitization, while at higher manganese levels the effect is reversed and the addition of manganese increases the stability of the carbide. Similar reversals are seen (in cast irons) in the case of aluminum, titanium, boron and other elements which react with oxygen and nitrogen, both carbide stabilizers.

Because of these and other complicating factors it is not possible to correlate composition and graphitization susceptibility in a series of specimens in which several elements are varying simultaneously, as an attempt at multiple correlation of the data in Reference 7 will show, but rather the more laborious classical method of isolating the variables and varying them singly must be used.

Table 1

Element	*Effect on graphitization*
Hydrogen	Strong carbide stabilizer
Oxygen	Strong carbide stabilizer (?)
Sulfur	Strong carbide stabilizer
Nitrogen	Weak carbide stabilizer
Phosphorus	Weak carbide stabilizer
Silicon	Moderate graphitizer (through deoxidation?)
Aluminum	Strong graphitizer in small amounts (through deoxidation and denitridation?)
Nickel	Weak graphitizer
Cobalt	Weak graphitizer
Copper	Weak graphitizer
Molybdenum	Weak carbide stabilizer
Manganese	Strong carbide stabilizer
Chromium	Strong carbide stabilizer

Table 1 summarizes the effect of the more important elements on graphitization in steel from evidence scattered widely through the literature (and in the case of cobalt, nickel and copper, from studies on cast iron). The important element here whose effect is most in doubt is oxygen. It is generally believed to be a strong carbide stabilizer in cast irons, and there is some evidence that it acts similarly in steels, though the evidence is confused.

If our knowledge of the true effect of many of the important elements on graphitization in steel is in a state far from perfect, the theory to account for these effects is in a far worse state. The old sulfide film theory* and the rationalization based upon the apparent correlation between lattice types of the alloys and effect on graphitization† are either unacceptably *ad hoc* or questionably relevant, and in either case entirely inadequate.

It is true that some alloying elements alter somewhat the rate of diffusion of carbon through austenite, and presumably also through ferrite, but this has not been measured. The effect in austenite is small, however, and it does not correlate with the effects on graphitization, so that it would be very surprising to find it possible to base any theory upon effects on carbon diffusivity.

It is also true that vacancies must diffuse to the graphite to provide room for its growth, and alloying elements would probably have an effect on this; this diffusion rate does not, however, influence graphitization rate, as is witnessed by the lack of rate preference near free surfaces.

In rationalizing the effects of alloying elements one might consider the thermodynamic approach—the effect of the alloy on the driving force under which the carbon migrates from carbide through the ferrite to the graphite.‡ This potential is in fact the separation of the graphite solvus from the carbide solvus and is labeled Δ in Fig. 6. The true course of the graphite solvus line is not known for the binary alloy, and certainly the effects of third elements upon both solvus lines are not known, so that no progress can be made along this line with the data at hand.

Since the pertinent equilibrium diagram data are lacking upon which to build a systematization of the effects of alloying elements, the alternative mechanistic approach might be considered. This requires a knowledge of the distribution of the third element among the ferrite, graphite and carbide phases. About all that can be said about the possibility of metallic atoms being in the graphite phase is that potassium and sodium will enter the graphite lattice under suitable

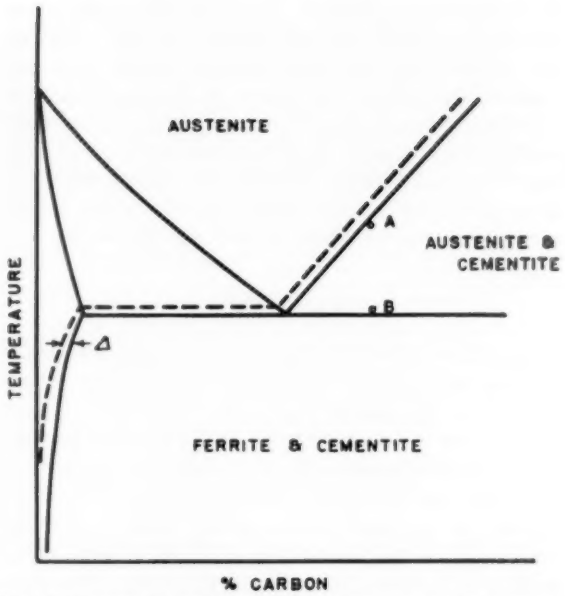


Fig. 6 Corner of iron-carbon diagram. Δ is the concentration differential in the ferrite associated with graphitization

conditions; but nothing at all is known about whether chromium, aluminum or manganese, which inhibit graphitization, or any other pertinent elements can or do enter the graphite phase in steel and affects its stability. The state of knowledge of the location of third elements in a ferrite-cementite structure is in very much better condition, due in large measure to Hultgren and co-workers,[8] whose distribution ratios for steel at 700° C are summarized in Table 2. It is possible that these ratios, which in the main were determined in essentially ternary alloys, may not always hold true when other elements are present in large amounts.

The suggestion has been made[9] that there is a distortion of the cementite lattice by the presence of alloy atoms and that this distortion, affecting the stability of the metal-carbon bonding in the cementite, may correlate with the observed effect of the alloy addition upon graphitizing behavior. The suggestion is essentially untested though the correlation by rank between the distribution ratios of Table 2 and the effects of these elements on graphitization recommends that it be examined further.

Table 2

Element	*Distribution ratio (cementite:ferrite)*
Aluminum	0:1
Phosphorus	0:1
Silicon	0:1
Copper	0:1
Cobalt	0.23:1
Nickel	0.3:1
Tungsten	2:1
Molybdenum	8:1
Manganese	11:1
Chromium	28:1

* This "theory" proposed an invisibly thin sulfide film enveloping carbides and retarding escape of carbon; the film was coagulated by graphitizing elements and strengthened by carbide stabilizing elements.

† Face-centered elements such as aluminum and nickel in general promote graphitization while body-centered elements such as chromium and molybdenum stabilize carbides.

‡ Although graphite was pictured above as being nucleated probably at a carbide interface, it is not nucleated at every carbide, and during its growth carbon must diffuse from other carbides through the ferrite.

Because of the strong and diverse effects exerted by many elements on graphitization even sometimes in small amounts, and because of possible complex interaction of impurities and alloys, it seems particularly desirable, practical and timely to pursue further a theory to account for these effects.

ACKNOWLEDGMENTS

The original graphitization data were taken incidental to heat treatments in connection with Project TF4-901(202) supported by the Ordnance Corps, Department of the Army. The steel was supplied by the U. S. Steel Corp. through the kind cooperation of Dr. G. V. Smith.

References

1. White, Albert E., "Graphitization of Steels at Elevated Temperatures," *Metal Progress*, **52**, 371 (September 1947).
2. Morrogh, H., and Williams, W. J., "Graphite Formation in Cast Irons and in Nickel-Carbon and Cobalt-Carbon Alloys," *Jnl. Iron Steel Inst.*, **155**, I, 322 (1947).
3. Brown, F., "The Prebaking Effect in Malleabilizing," Am. Foundrymen's Society (to be presented in 1954).
4. Hultgren, Axel, and Edstrom, Olov, "Graphitization of Martensite on Heating," *Jernkontoret Ann.*, **126**, 383 (1942).
5. Brown, F., Doctoral Dissertation, Carnegie Institute of Technology, 1950.
6. Fiorentino, R. J., Hall, A. M., and Jackson, J. H., "Effect of Certain Elements on the Graphitization of Steel," ASME Paper 53-A-153 (1953).
7. Austin, Charles R., and Fetzer, M. C., "Factors Controlling Graphitization of Carbon Steels at Subcritical Temperatures," *Trans.* ASM, **35**, 485 (1945).
8. Hultgren, Axel, and Co-workers, "Isothermal Transformation of Austenite and Partitioning of Alloying Elements in Low Alloy Steels," *Kgl. Svenska Vetenskapsakad. Handl.*, **4**, No. 3, Page 3, (1953).
9. Brown, F., and Hawkes, M. F., "Kinetics of Graphitization in Cast Iron," *Trans.* AFS, **59**, 181 (1951).

Exploratory Tests of the Air-Carbon Arc Cutting Process

For removal of defective areas from metal parts and for back gouging of welds in steel, stainless steel and aluminum, this process holds considerable promise

by A. R. Hard

IN THE Arcair metal-cutting process an arc is drawn between a carbon electrode and the work. Two jets of compressed air coming from one clamping jaw of the electrode holder are directed axially along the electrode and remove parent metal as it is melted by the arc. It appears that most of the cutting action is physical rather than chemical. The process is not limited to plain steel, but has been used on stainless steel, aluminum and even magnesium. Although the Arcair torch can be used for actual severing, the cut edge quality is not generally competitive with that of the oxy-acetylene torch. Where a U-shaped gouge is desired the process does a uniform job at a high rate of speed. For removal of defective areas from metal parts and for back gouging of welds the process should find considerable application.

The power cable of the torch is connected to the positive terminal of a standard welding generator of about 400 amp capacity. An air supply of 80 to 100 psi is connected without a pressure regulator. Normal shop pressure fluctuations have no noticeable effect on the cutting action. At the time of this investigation electrodes were available either plain or copper coated in diameters of $^5/_{16}$ and $^3/_8$. Larger and smaller electrodes have since been made available. Copper-coated electrodes are generally used since air blowing past a bare electrode soon tapers it to a sharp point. The resulting gouge will tend toward a V rather than a U shape and the width of the cut may decrease considerably. The tapered electrode must be carefully manipulated to avoid breakage.

Any cutting or welding process which might change the carbon content of the metal on which it is used is naturally open to question. With copper-coated electrodes there is also the possibility of introducing copper into the parent metal. To evaluate some of these factors a series of tests was made on $^3/_8$-in. mild steel and type 304 stainless steel plate stock as outlined in Table 1.

The current values selected for these tests are representative of normal, high and low values resulting in normal-, high- and low-speed metal removal. Metallographic sections were made on all of these cuts. From each section a tracing of the cut and its heat-

A. R. Hard is Associate Research Engineer, The State College of Washington, Pullman, Wash.

Table 1

Specimen No.	Plate material	Electrode		Current, amp.	Welded before sectioning	Sampled for chemical analysis
		Size, in.	Type			
1	M.S.	5/16	Plain	235	..	X
2	M.S.	5/16	Plain	275	..	X
3	M.S.	5/16	Plain	125	..	X
4	M.S.	5/16	Plain	225	X	..
5	18–8	5/16	Plain	200	..	X
6	18–8	5/16	Plain	280	..	X
7	18–8	5/16	Plain	180	..	X
8	18–8	5/16	Plain	220	X	..
13	M.S.	5/16	Cu coated	270	..	X
14	M.S.	5/16	Cu coated	430	..	X
15	M.S.	5/16	Cu coated	200	..	X
16	M.S.	5/16	Cu coated	230	X	..
17	M.S.	3/8	Cu coated	335	..	X
18	M.S.	3/8	Cu coated	400	..	X
19	M.S.	3/8	Cu coated	265	..	X
20	M.S.	3/8	Cu coated	335	X	..

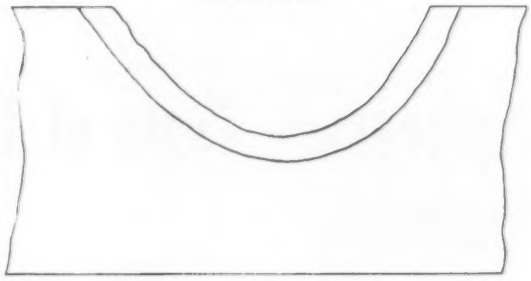
affected zone was made at 10 diam using a microprojector. Areas of the gouges and the heat-affected zones were then determined by means of a planimeter. The traces for Specimens 2 and 14 are shown in Figs. 1(*a*) and 1(*b*). Although these two cuts were made at different current settings the general shape of 1(*a*) is typical of gouges made with the copper-coated electrodes and 1(*b*) is typical of gouges made with a bare electrode which has become tapered after a slight amount of use.

From the data on areas of the gouge and the heat-affected zone given in Table 2, no trend toward a deeper or more shallow heat zone at different current settings can be observed. Apparently, the operator adjusts his cutting rate to compensate for the current setting. Our experience in this respect does not indicate that departure from normal operating conditions is to be favored.

The surfaces of the grooves were sampled for carbon determination. The problem of sampling such a specimen introduces variables which leave the final figures open to some question; but since additional tests were contemplated the method was used on an exploratory basis. Only the most uniform section of each cut was sampled. Before sampling, each specimen was hand wire brushed to remove any loose particles not actually retained in the surface of the cut. In sampling, a shallow cut was made in the gouge using a pointed shaper tool. Due to irregularities in the gouge it was not possible to remove all the surface of a given cut and, to avoid undue dilution, the sampling was stopped when much of the original surface was still visible. The sample chips were degreased with ether and dried with acetone. Standard ASTM procedure for carbon determination in steel was used. The result of this series of determinations is given in Table 2.

The most disturbing figure in this table is the 0.68% carbon of Sample 13. No correlating factor which would explain this high figure was observed. In some subsequent work oscillographic records of current and voltage taken during cutting showed that very smooth

Figure 1(a)



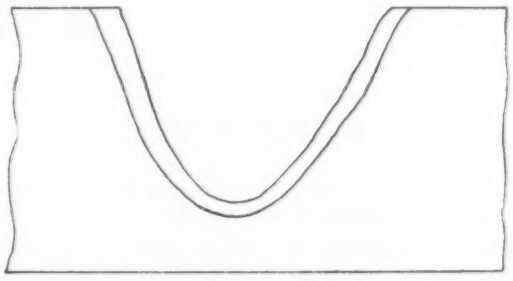


Figure 1(b)

gouges resulted in a voltage fluctuation between 45 and 60 and a current fluctuation between 325 and 400 amp. The frequency of the fluctuation was 100 cps and higher. In addition, occasional short circuits were noted. It is possible that further work along this line would show a correlation between the number of short circuits and the carbon content. Some specimens show a slight decrease in carbon which could result from the air blast on the hot steel, but in most cases the carbon decrease is not significant.

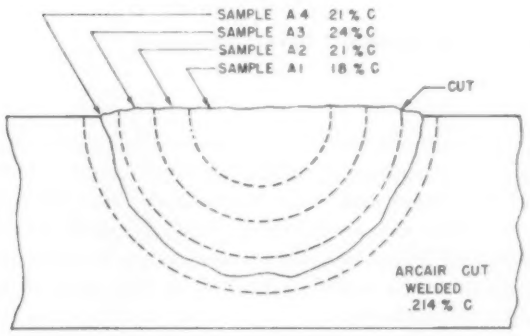
In order to improve the uniformity of the gouges for test purposes, some experimenting was done with the torch mounted on a cutting-torch carriage. Since the rate of carbon consumption is not high, it was possible to feed the carbon manually and obtain very uniform and well-contoured cuts. One cut which meas-

Table 2

Specimen No.	Plate matl.	Electrode Diam, in.	Electrode Type	Current, amp	C, %	Area cut, sq in.	Area heat zone, sq in.	Heat-Zone % of cut
1	M.S.	5/16	Plain	235	0.25	0.412	0.144	35
2	M.S.	5/16	Plain	275	0.33	0.666	0.190	28.5
3	M.S.	5/16	Plain	125	0.35	0.424	0.146	34.4
				Parent metal	0.33			
5	18–8	5/16	Plain	200	0.09	0.903	...	0.2
6	18–8	5/16	Plain	280	0.10	0.695	...	0.2
7	18–8	5/16	Plain	180	0.10	0.564	...	0.2
				Parent metal	0.11			
13	M.S.	5/16	Cu coated	270	0.68	0.472	0.198	42
14	M.S.	5/16	Cu coated	430	0.31	0.548	0.258	47
15	M.S.	5/16	Cu coated	200	0.28	0.475	0.246	51.8
				Parent metal	0.16			
17	M.S.	3/8	Cu coated	335	0.25	0.315	0.139	44.2
18	M.S.	3/8	Cu coated	400	0.29	0.390	0.149	38.2
19	M.S.	3/8	Cu coated	265	0.27	0.575	0.243	42.3
				Parent metal	0.22			

ured 1/2 in. wide and 1/4 in. in depth was selected for a weld deposit test. Using a standard milling cutter a duplicate of the Arcair groove was prepared in the same plate. Both grooves were filled with GE W-27 electrode. The first and last inch of each weld was then discarded and the remaining 4 in. of weld deposit sampled as indicated in Figs. 2(*a*) and 2(*b*). The oscillogram for this cut showed 19 short circuits in the portion retained for sampling. This is higher than usual for cuts made with the mechanical travel and is more characteristic of hand operation. The results show an over-all average carbon increase of about 0.04% carbon in the Arcair cut.

Figure 2(a)



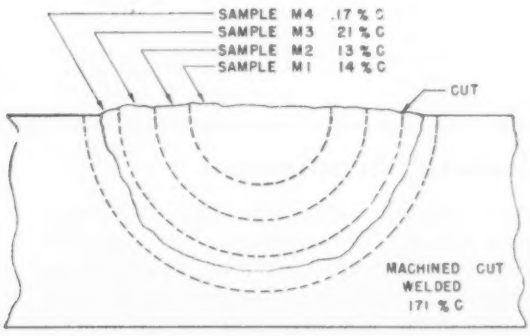


Figure 2(b)

BEND TESTS

Root-bend specimens were prepared in low-carbon steel using 3/8-in. plate with a double-V edge preparation. After welding the face side of each of two panels with GE W-27 rod, one was back gouged by the Arcair process and the other back chipped with a pneumatic hammer. The root welds were then made and two duplicate specimens cut from each panel.

A similar set of specimens was prepared in Type 304 stainless steel welded with Chromend K electrode.

None of the root-bend specimens showed any failure during testing.

Side-bend specimens were prepared in 1-in. low-carbon steel plate. Back gouging was performed in one set by the Arcair process and in the other with a chipping hammer. The bend specimens are shown in Fig. 3. The Arcair specimens in this group showed ductility equal to that of the mechanically chipped specimens.

An attempt was made to determine copper pickup in the parent metal caused by the use of copper-coated carbon cutting electrodes. Spectrographic analysis failed to show any significant change. It was later discovered that there is a slight amount of copper which is transferred from the electrode to the surface of the cut. Generally this is not noticed since the surface of the copper is oxidized. Sand blasting will remove the copper oxide making the copper readily apparent. The deposits take place in a random manner. In one typical plate containing eight 6-in. cuts, four cuts showed no copper at all. The total area of copper in the 4 ft of grooves would total less than 1/2 sq in.

CONCLUSIONS

For many applications the amount of carbon introduced by the Arcair gouging process should not be serious. In low-carbon steel and Type 304 stainless

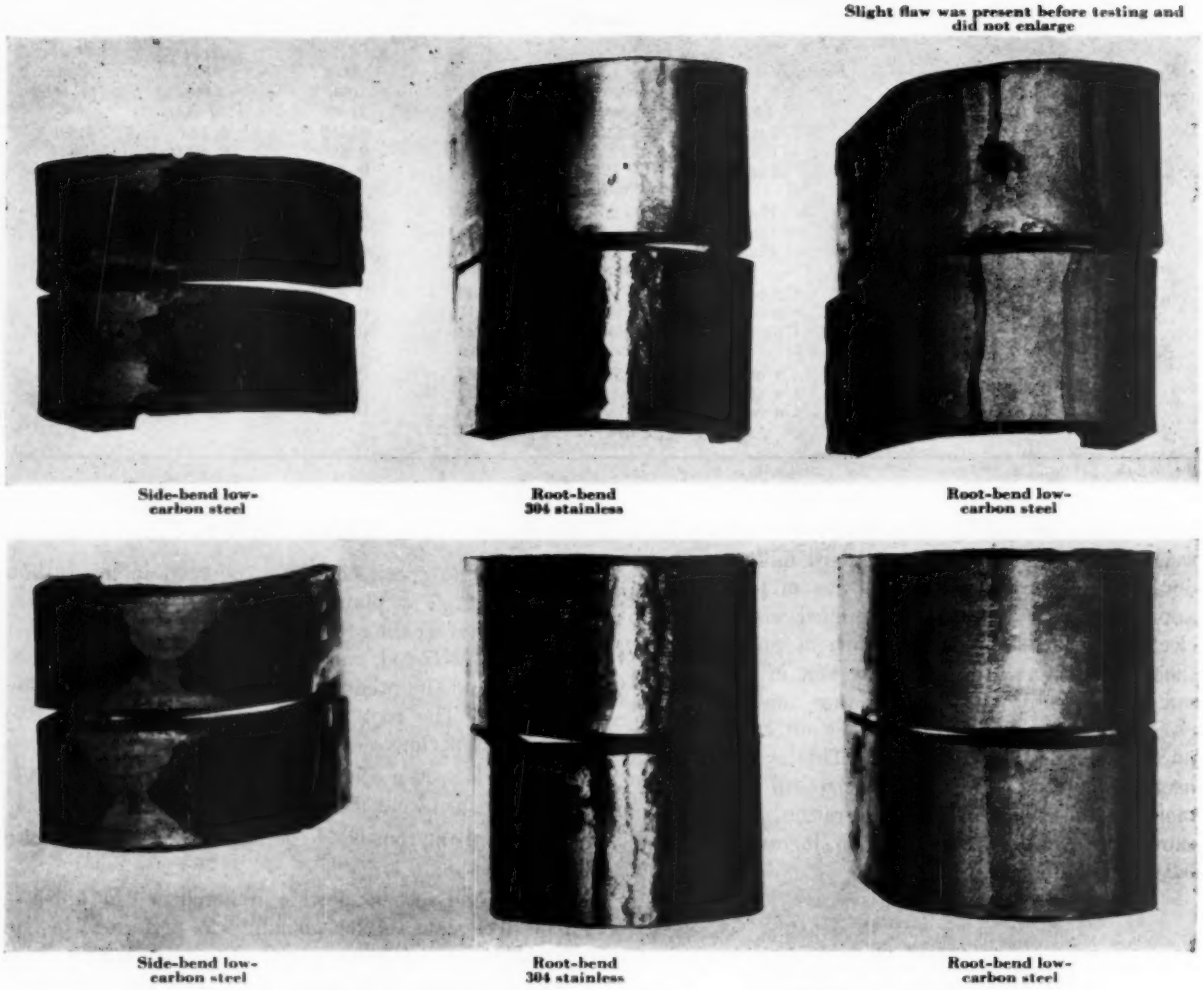

Slight flaw was present before testing and did not enlarge
Side-bend low-carbon steel
Root-bend 304 stainless
Root-bend low-carbon steel
Side-bend low-carbon steel
Root-bend 304 stainless
Root-bend low-carbon steel

Fig. 3 Specimens (top) mechanically back chipped; specimens (below) Arcair back gouged

steel satisfactory bend tests were obtained. A test of deposited weld metal showed an average increase of 0.04% carbon due to the process.

Although copper contamination of the parent metal is a possibility, the amount of copper introduced appears to be very small and no detectable change was observed in spectrographic analysis.

For future test work on this process the use of automatic or semiautomatic operation would result in more uniform gouges and make more reliable samples possible. Since the possibility of correlating short circuiting and carbon pickup was not realized at the time the program was in work, an interesting field remains for future investigation.

Bound Volumes Welding Research Supplement

An inventory of the bound volumes indicates that the Welding Research Council could spare a few bound volumes for certain years. The Council proposes to dispose of these volumes as long as they last at $15 per volume. Each volume is bound in imitation leather covers and contains an index. Each volume probably represents more than a million dollars worth of research. Volumes for the following years are still available: 1939, 1940, 1941, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952 and 1953.

Fatigue as a Factor in Pressure Vessel Design

The resistance of pressure vessels to repeated loading is discussed and appraised in interpretive report sponsored by the PVRC

by T. J. Dolan

Summary

The factors influencing the fatigue strength of metal members are discussed from the viewpoint of their applicability to design of pressure vessels. Stress range and number of cycles of loading are of primary importance in determining whether fatigue failure may develop. The types of blemishes, notches or recesses in the contour determine the severity of the peak stresses from which progressive fractures will initiate if the loading is repeated a sufficient number of times. Consideration is given to environmental conditions such as depressing the temperature which increases the fatigue strength, whereas raising the temperature to high levels induces creep and lowers the fatigue properties; erosion or corrosion are serious in producing microscopic pits that serve as severe stress raisers which produce fatigue damage and should be avoided wherever possible. Periodic rest periods of no load have no harmful effects on the fatigue resistance of a vessel. The presence of sound fusion-welded joints of high quality has no deleterious effects, but can lead to marked reductions in fatigue strength if improperly designed or if the weld contains undercuts, porosity, slag or poor fusion. In general, thick-walled vessels subjected to extremely high pressures are likely to be more susceptible to initiation of fatigue cracks than low-pressure thin-walled containers, but all vessels intended for long life and which are to be subjected to a large number of pressure fluctuations in service should be designed to insure adequate fatigue resistance by eliminating excessive stress-raisers and by carefully controlling fabrication and operating procedures. Fatigue data are statistical in nature being influenced by chance effects in sampling, manufacture, and testing; thus exact design procedures are not available and the designer must be satisfied by attaining a fairly high probability that the member will not develop fatigue failure within the normal service life. It is fortunate that small decreases in the peak stresses are accompanied by large increases in fatigue life, but the reverse is also true. Thus the elimination of severe stress raisers is the principal hurdle and is the most effective method of insuring safety against progressive fracture; if peak stresses are significantly reduced, the question of exact fatigue life becomes more of academic than of real interest.

T. J. Dolan is Head of the Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

This report has been prepared under the Sponsorship of the Materials Division of the Pressure Vessel Research Committee of the Welding Research Council.

INTRODUCTION

MOST of the service failures that occur in machine parts develop after many repetitions of load and appear as a gradually spreading microscopic crack which finally may lead to complete rupture of the part. Drastic fractures of this type are commonly referred to as fatigue failures although "progressive fracture" would be a more appropriate name to emphasize the gradual growth of a crack resulting during many cycles of repeated stressing. In the past the possibility of fatigue failure in common types of pressure vessels has been recognized and some instances of this type of failure have occurred; however, a few detailed studies of the importance of fatigue resistance of vessels have been published.*

The number of loading cycles sustained by boilers, tanks and many other types of vessels during their normal life can usually be counted in the thousands or, at most, in hundreds of thousands; in terms of fatigue this is a relatively short life. A high stress would be required to develop progressive fracture within this number of cycles. Laboratory tests indicate that most metal parts will usually withstand 100 or perhaps as many as 1000 repetitions of a load as much as 75% of their static ultimate strength. Hence, if only a small number of repetitions of the load are expected, the part might be designed on the basis of static strength alone.

The question is often raised as to whether fatigue failure is a dominant factor in the life of pressure vessels. At the present time it is difficult to find conclusive proof that many vessels have failed from repeated stressing. Why then is it necessary to study and appraise the resistance of vessels to repeated loading? Perhaps one of the strongest arguments would be that the resistance to fatigue is the major uncertainty in the performance of many types of modern pressure vessels that operate at room temperature or slightly elevated temperatures. Under present codes and specifications (with careful procedures in design, fabrication and inspection and with the requirement of a pressure test at $1^1/_4$ to $1^1/_2$ times the design pressure) most vessels when released for service have demonstrated their ability to withstand static load without failure. Furthermore, with modern treatment of boiler waters (or elimination of corrosive conditions in other containers such as process vessels), there is little likelihood of accumulation of severe damage from corrosive conditions that would make the vessel unsafe for static loads during the normal life of the vessel. However three other types of failure may still be possible, namely: (*a*) excessive deformation by creep at high temperature, (*b*) brittle fracture under suddenly applied load at low temperature or (*c*) progressive fracture from repetition of loading. If one rules out the high- and low-temperature fields, it seems apparent that one of the uncertainties remaining is the possibility of cracks developing during service from the many repetitions of loading that must be sustained by the vessel. That this is a real danger should be apparent from the many drastic failures that have occurred in all other classes of structures familiar to the engineer which, during normal service, have a large number of repetitions of load imposed. What is considered as "a large number" is somewhat indefinite. However for high ranges of cyclic strain, failures of bridge members, aircraft wings, railroad rails, etc. have been known to occur after several thousands of repetitions. Based on this experience, it seems obvious that pressure vessels of those types that must sustain many repetitions of loading are not immune to fatigue failure and hence the possibilities of progressive fracture must be given careful consideration.

The general consensus seems to be that few of the failures of pressure vessels have been directly attributable to fatigue. However, most of the outstanding cases of fatigue failure in service are traceable to conditions readily recognizable as poor from the fatigue viewpoint. In thin-walled *low-pressure* containers any pressure surges are usually well damped and the vessels are usually "overdesigned"

* References 5 to 9 at the end of this paper cover several instances in which the fatigue behavior of vessels has been analyzed.

by employing low design stresses. The principal areas of weakness (due to increased stresses around openings, pipe connections, knuckles and other abrupt changes in shape) may not be too severely stressed. In many of these vessels of conservative design the full properties of the metals are seldom effectively utilized and design is only sufficiently refined to avoid needless severe stress raisers. At present the main sources of trouble from fatigue usually arise from service-induced defects (see Fig. 1) or from auxiliary equipment such as pumps, compressors, valves, etc. However with increased life, high variations in operating pressure and a trend toward greater working stresses, safety of design requires elimination of needless stress raisers and consideration of the fatigue strength of the vessel as well as satisfying the usual static design criteria based on existing codes and specifications. Severe new requirements that may involve many cycles of pulsating load (from either internal pressure or repeated thermal stresses) are sometimes encountered by vessels in chemical processing, oil cracking, gas storage and other applications. Wherever a large number of repetitions of loading are involved, there is potential danger of fatigue failure.

For *extremely high-pressures* the thick-walled containers* are seriously affected by repeated loading and fatigue problems become the major deterrents to further progress in this field. Even the design of a simple cylindrical vessel to resist high pulsating pressures often meets with failure. Vessel performance cannot be predicted on the basis of static tensile properties of the material and rational procedures of a quantitative type have not been formulated for design of more complicated members (containing openings or changes of shape). Unfortunately the art is not sufficiently advanced to permit design for a specified life within close limits for even the simplest parts.

In the experimental testing of pressure vessels, Kooistra and Blaser[5] have raised the question as to whether a static test to fracture is truly representative of vessel performance. Certainly in the final stages of a test of destruction under static pressure, the large deformations and cold-working of the metal alter the conditions to the extent that one is not testing the same shape nor the same material as the original vessel. The fact that a vessel does not normally fail under the first application of a static pressure considerably exceeding the design load is not an assurance that it will never fail if such load is repeated a large number of times. Hence the difference in behavior of material under repeated loading should be considered by the designer to minimize possibility of progressive fracture caused by highly localized strains in complex details of the vessel components. For this reason, recent emphasis has been placed on testing pressure vessels under repeated loading from zero to a maximum pressure. Though this does not always simulate the actual operating conditions, the fatigue test is efficient in detecting severely stressed zones or weak spots in the vessel. In some cases it may serve the further purpose of demonstrating that the weakest sections of the vessel are actually strong enough to resist failure under thousands of cycles of a working pressure that exceeds the design loading. The fatigue test is a severe measure of the adequacy of design and has the advantage of testing the vessel in a shape that is not unduly distorted beyond operation.

There exist today so many different classes and operating conditions for pressure vessels that it becomes difficult to discuss the importance of the fatigue behavior in the wide variety of circumstances encountered. So many different variables are encountered in boiler drums, gas cylinders, chemical processing vessels, oil processing containers, etc., that no general statements are applicable to the whole field. Therefore this paper will be limited to a general discussion of some factors encountered in pressure vessels that influence their fatigue resistance.* Codes and specifications which are based on static load criteria are not adequate for judging the safety of a vessel subjected to repeated loading. In deriving design formulas, simpifying assumptions are made in predicting the magnitude and variation of the loading, in appraising the strength and uniformity of the metal, and in calculating the resulting stresses in the member. That is, an "idealized" set of conditions is selected which assumes: (*a*) that material is elastic, homogeneous and isotropic (*b*) that loads are applied only once (or a few times for which the detailed reaction of the member during each loading cycle is identical with that of the previous loading cycle) and (*c*) that the method of processing the member does not seriously alter the mechanical strength of the metal.

The calculated nominal stresses (based on these assumptions) are only crude approximations of those in commercial metal members but fortunately are usable for purposes of engineering design of ductile metal structures when the loads are reported only a few times. However, for members subjected to many repetitions of loading, the behavior of a commercial metal departs significantly from these idealized conditions. Damage accumulates during each cycle of loading and develops crystal-by-crystal until a large portion of a localized zone has its structure sufficiently disrupted to initiate microscopic cracks. The progressive fracture develops at localized regions of high stress and is nucleated by slip bands within poorly oriented or weaker crystals or at inclusions, phase boundaries, etc. Subsequent repetitions of loading cause the cracks to grow, join, and spread to final fracture of the member.

FACTORS INFLUENCING FATIGUE STRENGTH

There are no simple quantitative rules

* The term "thick-walled" vessel is meant to infer vessels designed to carry internal pressures that are large enough to be appreciable when compared with the tensile stresses in the shell. That is, the state of stress existing at the inner wall of the vessel is significantly affected by a compressive stress normal to the face whose magnitude exceeds some significant fraction of the circumferential stress in the shell. While it is difficult to set an arbitrary limit, one might suggest that normal pressures exceeding 10% of the circumferential stress produce sufficient change in the octahedral shear stress to become significant in altering the criteria for failure. For example, a vessel with only a 1/2-in. wall thickness might fall in the category of "thick-walled" or high-pressure container if the bore is small and the internal pressure for which it is designed exceeds about 10% of the working design stress for the metal.

Fig. 1 Failure of gas container initiated by fatigue

A nick (at point indicated by arrow) caused by handling in service developed fatigue damage under subsequent cycles of recharging and emptying. Final rupture occurred in an explosive manner. (National Bureau of Standards.)

* References 1 to 4 of the Bibliography contain rather complete presentations of the present-day knowledge of fatigue of metals.

for proportioning members to resist repeated loading; too many factors that are difficult to control will alter the fatigue properties. These principal influences may be grouped in general categories as follows:

1. The initial mechanical properties of the metal (a function of the chemical composition, method of production, subsequent heat treatments, and metallurgical structure in the various parts of the vessel after its completion).

2. The processing of the member (operations that influence the surface texture, residual stresses, plastic deformations, decarburization of the surfaces, etc.).

3. The size and geometrical shape of the member (affect not only the stress distribution and stress gradient but also the statistical chance of finding weaker crystals or zones in larger members).

4. The loading conditions (these control the actual biaxiality of the stresses developed and predetermine the relative magnitudes of the alternating stress superimposed during the loading cycle). The actual loading may have a complex nonrepetitive history (of the type shown in Fig. 2*b*); however most laboratory experiments are limited to a simple repetitive loading cycle such as that shown in Fig. 2*a*. Attempts are usually made to study the amount of alternating stress S_a that can be superimposed on a mean stress S_m without causing failure within an expected member of cycles predictable for the intended service.

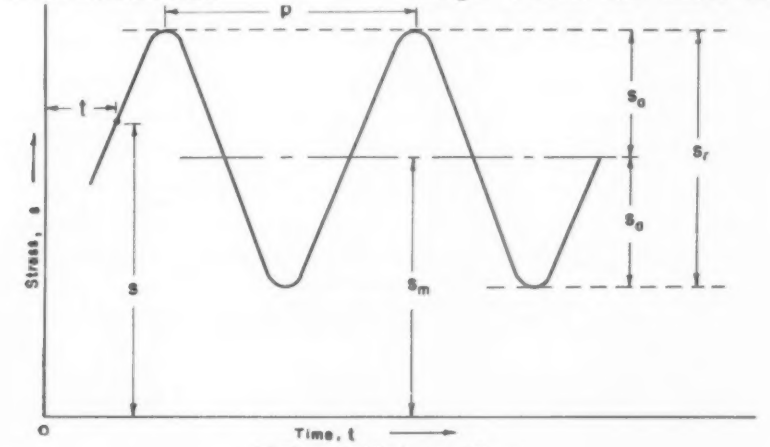
5. Environmental conditions often are a major factor (and include the presence of corrosive atmosphere or chemical attack, erosion, elevated temperatures, etc.).

The information available on fatigue properties of metals has been obtained primarily from laboratory tests in repeated tension or bending of small specimens in which the stresses are essentially unidirectional. The majority of data have been used to determine a "knee" for which the curve of S vs. N approaches a horizontal asymptote (see Fig. 3*a*) and the ordinate to which is called the "*fatigue limit*" or "*endurance limit*". Presumably stresses below this limit do not cause fracture even though repeated an indefinitely large number of times. However for nonferrous metals (Fig. 3*b*) no sharp break occurs in the curve and a "*fatigue strength*" is arbitrarily designated as the stress ordinate corresponding to a large member of cycles (for example 500 million). Fatigue data from conventional laboratory tests are generally not directly applicable to vessel design because of differences in shape, size, finish and processing treatment as well as difference in loading conditions and severity of stress concentrations and residual stresses. Furthermore no satisfactory relationships exist to predict with accuracy the fatigue properties of a metal from a knowledge of the *static* mechanical properties. For pressure vessels the material selection is usually dictated by considerations other than maximum fatigue strength. However tests indicate that selection of material is not nearly as important in obtaining satisfactory fatigue resistance as is the exercise of care in the design, fabrication and operating conditions.

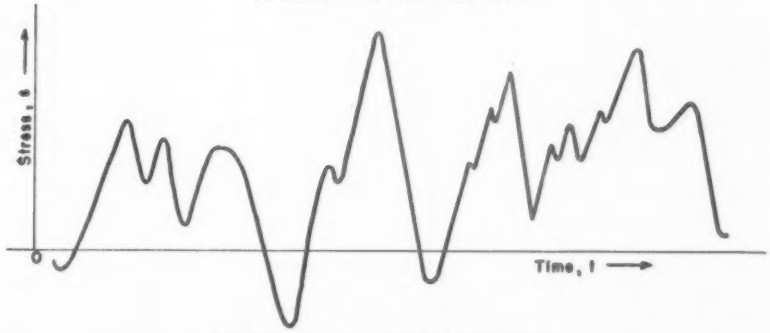
For pressure vessels there are few service conditions for which the loads are repeated millions of times. Hence the zone that is of primary interest is the "finite life" (below about 100,000 cycles of loading). For example about 87,600 cycles would be developed in a vessel in full-time operation for 40 years if the pressure cycle were repeated every four hours. This finite life region of the S–N diagram has not been emphasized in the majority of studies of fatigue properties of metals.

Of the many environmental conditions encountered, perhaps the one most effective in reducing fatigue strength is the presence of mildly corrosive liquids or gases in contact with the metal *while it is stressed repetitively*. The "corrosion-fatigue" strengths of metals are only about two-thirds to one-ninth of their fatigue strengths in air. However, this subject has been covered by Copson[11] in a previous monograph; and, hence, will not be further discussed here.

Erosion effects are similar to those of corrosion in depending upon severity and time to build up a nick or notch from which fatigue failures may propagate. For example, White[8] describes changes in a high-pressure drum required to reduce cracking in fatigue from corrosion and erosion effects. The principal influence of erosion may be regarded as that of setting up a local notch with altered surface finish; the quantitative effects are much the same as those described in the next section on "stress raisers." Elevated temperature is another important environmental factor in affecting the stress distribution and the properties of the metal when deviations are made from room temperature operation; the effect of high and low temperature on fatigue strength will also be discussed in a later portion of this paper.



(*a*) Sinusoidal Variation of Stress



(*b*) Complex (Non-repetitive) Stress History

Fig. 2 Contrast between types of dynamic stress history

STRESS RAISERS AND NOTCH-SENSITIVITY

Any abrupt step or recess in the surface (such as at a drumhead, reinforced opening, bracket, pipe connection, etc.) constitutes a "stress raiser" that may serve as a nucleus for a fatigue failure. Stress raisers cannot be entirely avoided since they may occur as: (*a*) a metallurgical notch inherent in the metal due to segregation, inclusions, blow-holes, laminations, quench cracks, (*b*) a mechanical notch caused by the changes of contour necessary in a member for its functional use or (*c*) a service notch developed by corrosion pits, nicks, erosion or fretting. When progressive fractures occur they invariably develop from stress raisers; the *nominal* calculated stresses are frequently below the static elastic strength of the metal. Once started, the crack itself is a very

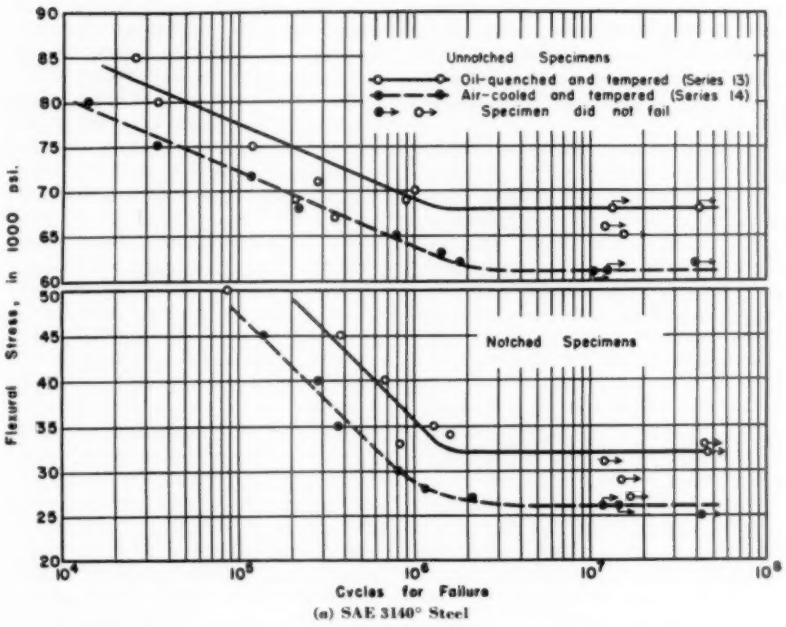
severe stress raiser that tends to be self-propagating during repetitions of the loading.

In tests of vessels subjected to repeated internal pressure, Moore[9] found that presence of local material defects or of tapped holes for a gage connection in the shell diminished the fatigue strength materially and resulted in premature failures. A stress raiser such as a hole was particularly dangerous when located in a welded joint.

Engineers have used mathematical and other theoretical methods (such as photoelastic analysis or elastic strain measurement) to determine the peak stresses developed by geometric changes in shape in simple members For example, the stresses around a hole in a plate, in knuckles, and fillets have been analyzed. However laboratory tests indicate that the effective reduction of fatigue strength is frequently somewhat smaller than is indicated by the theoretical stress concentration factor* (commercial metals depart from the idealized conditions assumed in the theoretical analyses). Thus engineers have come to regard the proportionate strength reduction caused by a stress raiser as a measure of the fatigue "notch-sensitivity" of the metal but it is difficult to find a uniformly acceptable basis for its evaluation. For example, two different metals are tested with a hole that develops a theoretical stress concentration factor of 2; it is found that metal A has its fatigue strength reduced by a factor of 1.9 and metal B has its strength reduced by a factor of 1.6. Metal A is thus regarded as being more notch-sensitive than metal B.

Researchers have attempted to relate notch-sensitivity to other properties that might be evaluated quantitatively such as plasticity, damping capacity, cohesive strength, work-hardening capacity and statistical theories of behavior. No single quantitative relationship between theoretical and effective strength reduction has proved satisfactory except in empirical fashion over limited ranges of variables. Low-carbon steels are generally regarded as being less notch-sensitive than high-carbon and heat-treated alloy steels, but this impression is obtained from comparisons of fatigue limits and may not be true on the basis of relative strength for a short fatigue life. For example, Bowman and Dolan in biaxial fatigue tests of $^3/_8$-in. plate[42] find the relative strength reduction due to a notch in A201 steel to be more drastic for a finite fatigue life than that in higher strength A302 steel.

* For example, a small circumferential notch in the "notched specimens" of Fig. 3a reduced the fatigue limit from 68,000 to 32,000 psi. This is a strength reduction factor of 2.12 as compared with the theoretical stress concentration factor of 2.9 from Neuber's[38] monograph.



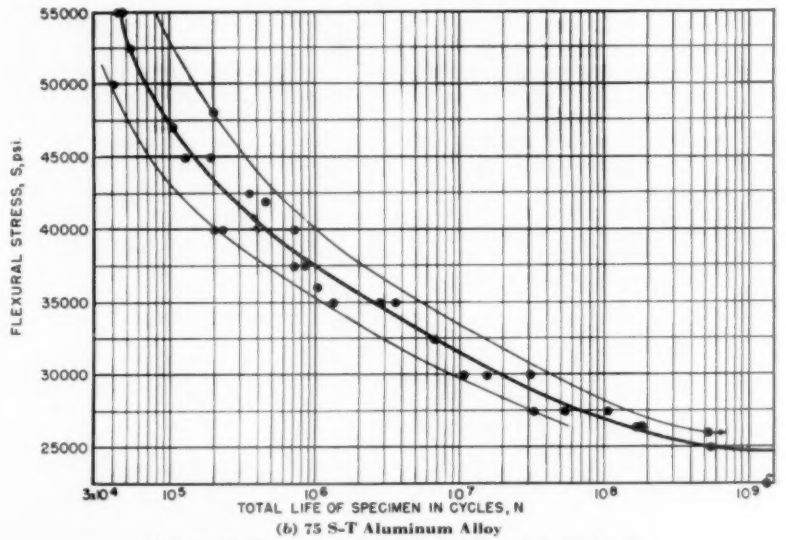


Fig. 3 S–N curves for rotating beam fatigue tests

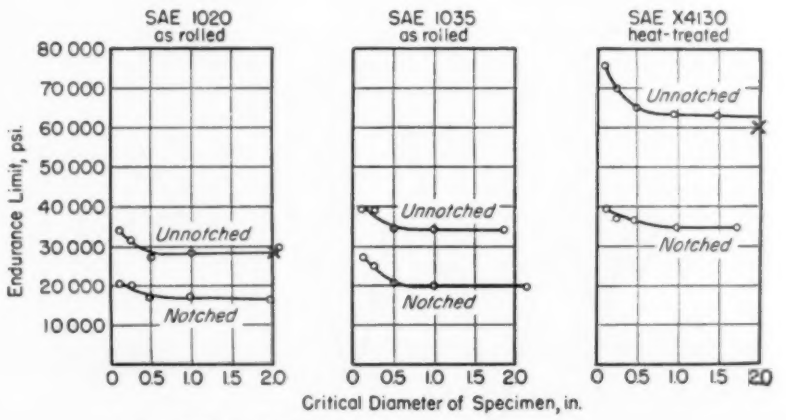


Fig. 4 Effect of size of specimen on endurance limit in reversed bending. Morkovin and Moore[39]

Notch-sensitivity in fatigue bears no relation to that in single-blow notched-bar impact tests; the fracture phenomena involved in the two types of loading are quite different. Fracture under a single impact is not dependent upon the cumulative chance effects developed during the repetitions of load that are of paramount importance in the submicroscopic phenomena leading to cracking in fatigue. No direct functional relationship was found by Yen and Dolan[15] between the concepts of notch-sensitivity in fatigue and those in the Charpy impact test; direct correlations do not seem feasible. For example, lowering the temperature of testing a ferrous metal will *increase* its fatigue strength,[35] but usually results in a marked *decrease* in Charpy impact values.

In general large members exhibit lower fatigue strength and sometimes a greater notch-sensitivity than do small members as is indicated in Fig. 4. This "size effect" for shafting subjected to bending or to torsion is *in addition* to any decrease in strength due to altered metallurgical conditions of the metal (caused by differences in forging, inadequacy of heat treatment in big sections, etc.). The effective strength reduction due to a notch in a large member often tends to approach that indicated by the theoretical stress concentration factor. That is, as the size of the member is increased, the ratio of the unnotched to notched endurance limits for data of the type in Fig. 4 usually tends to approach the stress concentration factor obtained from theoretical analyses based on elasticity. It is not known whether large or thick-walled pressure vessels will also exhibit a similar size effect, but the trends indicate that full values of theoretical stress concentration should be assumed for large thick members.

INFLUENCE OF RANGE OF STRESS ON FATIGUE STRENGTH

Fatigue fractures are developed primarily by the *stress variation;* the severity of loading must be judged mainly by the value of the alternating stress S_a (or the range of stress S_r, see Fig. 2). Since pressure vessels are rarely subjected to reversed loading conditions, the pressure fluctuation (or stress range) rather than the mean pressure is of major importance in design for resistance to fatigue. In most pressure vessel operation the nominal cycle varies from zero (or a small tensile stress) to some maximum tensile stress. However in some critical regions (of knuckles or reinforced openings) a partial reversal of stress may occur on unloading, and thermal stress gradients may produce significant mean or alternating stresses that must be considered as a portion of the loading.

Diagrams of the type in Fig. 5 have been used to study the effect of mean stress on the fatigue strength of metals. The value of the alternating stress S_a (that is superimposed on the mean stress S_m) is usually employed to represent the fatigue strength. Some investigators prefer to report the maximum and minimum stresses or the "range ratio" of minimum to maximum stresses in the cycle; hence, care must be used in selecting values for design purposes. In general, the data of Fig. 5 indicate that the allowable range of stress decreases somewhat as the mean stress in the cycle is increased to high values. The straight line shown in Fig. 5 lies somewhat below the data for most of the metals plotted, but may be expressed by the equation $S_a = S_r(1-S_m/S_u)$, to represent a line on the conservative side of the general trends indicated by specimens subjected to axial or bending loads; in this relation S_u represents the static tensile strength. This equation would also be representative of the conventional "Goodman diagram" which was originally devised to show that the effect of stress range was to decrease the allowable fluctuation linearly as the maximum stress was increased to the ultimate tensile strength. However in tests at large plastic strains, Gross, Tsang and Stout[27] concluded that the strain range per cycle appeared to have about the same effect whether applied in one direction only or in balanced reversed bending; others have reported similar effects indicating that the mean stress has relatively small influence on the fatigue strength under the usable range of loading conditions. Thus for most pressure vessel design, the fatigue strength for a zero to maximum load cycle would be representative of the allowable range of stress (if the same biaxiality of stress conditions existed in the test samples as in the vessel).

Most of the available fatigue data have been obtained with particular emphasis on specimens subjected to millions of cycles of stress; only a paucity of data exist for fatigue behavior in the range of 5000 to 100,000 cycles that would be of most interest for the design of pressure vessels. However a few compilations of data on fatigue strengths of laboratory specimens[27, 36, 37, 40] contain much information that is useful in a qualitative way. For example, compilations of the type shown in Fig. 6 are useful in comparing the relative strength reduction due to notches in the limited life region. More research is needed in this area and much useful information is being obtained in current studies being sponsored by the Pressure Vessel Research Committee.

Several investigations[36, 37] have indi-

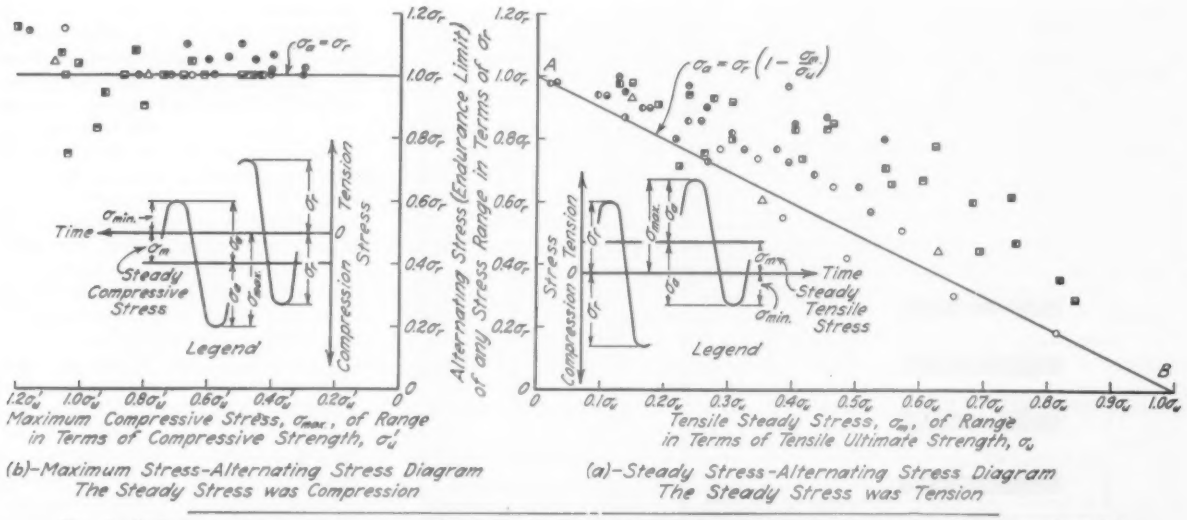

Alternating Stress (Endurance Limit) or any Stress Range in Terms of σ_r
Maximum Compressive Stress, $\sigma_{max.}$, of Range in Terms of Compressive Strength, σ_u'
Tensile Steady Stress, σ_m, of Range in Terms of Tensile Ultimate Strength, σ_u
$\sigma_a = \sigma_r$
$\sigma_a = \sigma_r\left(1-\frac{\sigma_m}{\sigma_u}\right)$
A
B
Time
Steady Compressive Stress
Steady Tensile Stress
Compression
Tension
Stress
Legend
(b)–Maximum Stress-Alternating Stress Diagram The Steady Stress was Compression
(a)–Steady Stress-Alternating Stress Diagram The Steady Stress was Tension

Fig. 5 Influence of mean stress on endurance limit for 13 ductile metals subjected to axial stress. Smith[16]

Note: **The symbols σ used to designate stress in Smith's illustration have the same meaning as the values S shown in Fig. 2. It will be noted that the diagonal line A-B is equivalent to the conventional "Goodman diagram" in which the maximum and minimum stresses of the cycle are plotted as straight lines on the ordinate scale and converge to intersect at the ultimate strength.**

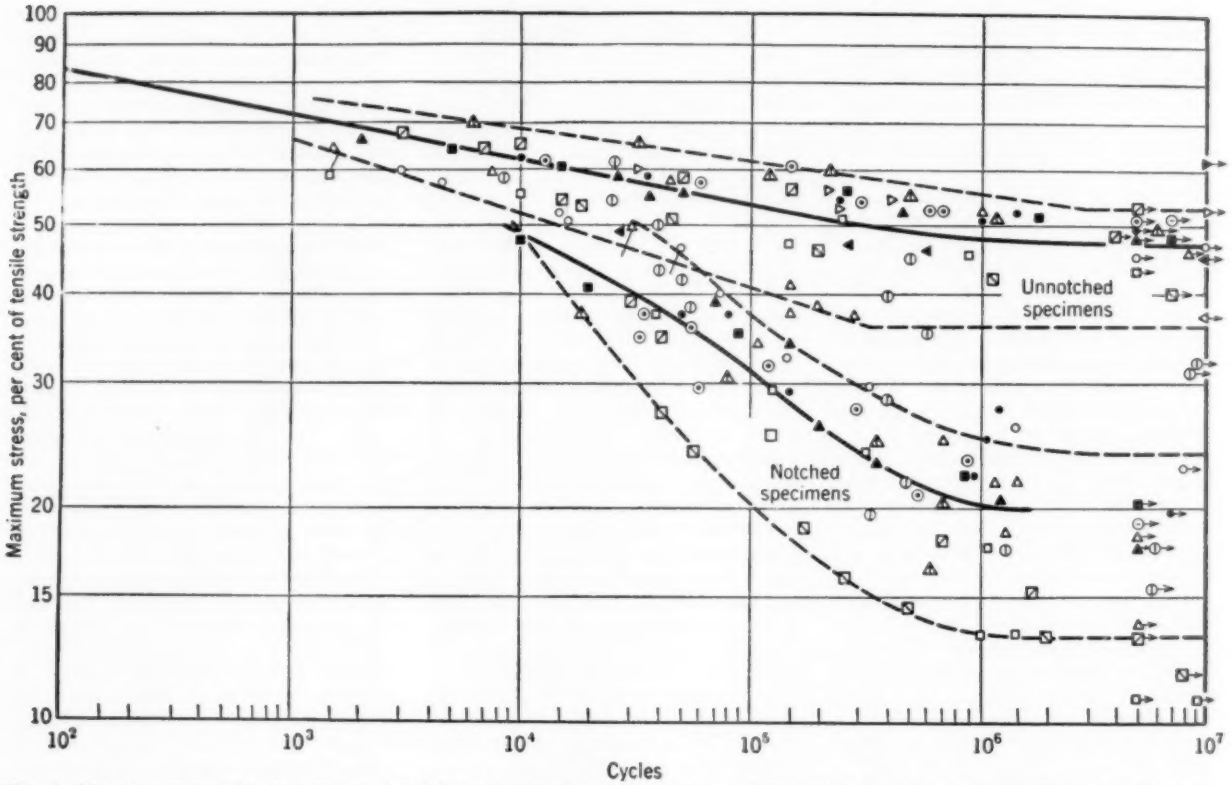


Fig. 6 Relationship of fatigue strength to life for reversed axial bending. Compilation of data on several metals by Weisman and Kaplan[37]

cated data of the type shown in Fig. 7 in which the curves for notched and unnotched steel specimens tend to converge as the number of cycles decreases. That is, the effective strength reduction caused by a notch is much decreased for the lower values of fatigue life. However this may not always be the case for other metals or other types of stress conditions; some tests show little change in severity of strength reduction over a range of values of fatigue life.[40, 42]

For purposes of design, the uncertainties in loads or in methods of calculating significant stresses, and unavoidable alteration in material properties during fabrication make it necessary to reduce the design stresses considerably below those which define the limiting or failure conditions. Any excess pressures which occur in vessels in service would normally increase both the mean and the alternating stress. Since progressive fracture is most closely associated with the alternating stress, the optimum method of insuring safety would be to reduce the amplitude of the alternating stress by a suitable factor of safety. However an increase in thickness of the shell that reduces the maximum stress due to internal pressure also reduces the magnitude of the mean and minimum stresses by the same proportion.* Hence the design may become safer because of two factors: the decrease in range of stress, and the slightly greater allowable alternating stress at the lower mean stress.

In general, for design computations the nominal *mean* stress S_m (Fig. 2) is ordinarily not corrected by multiplying by a stress concentration factor even though stress raisers are present. Although it does not appear entirely rational to apply a concentration factor only to the alternating component of stress S_a this method of analysis seems to give the best correlation with available test data. No set rules of design for members subjected to various ranges of repeated stress have re-

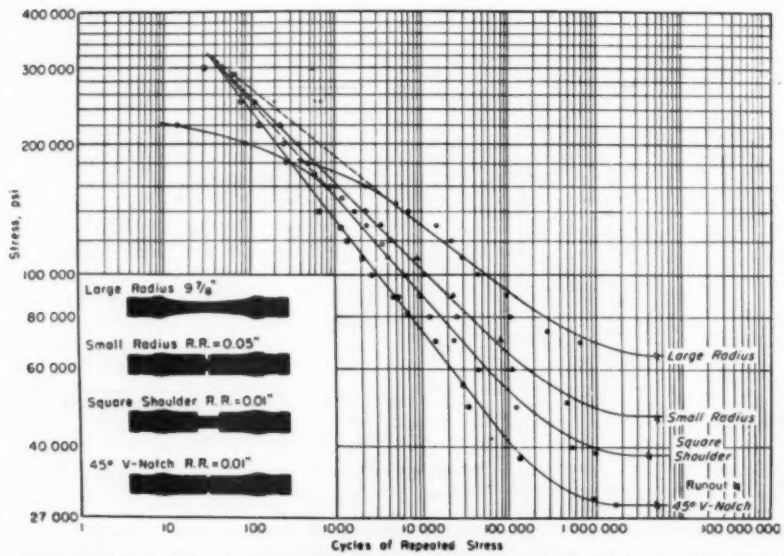


Fig. 7 Relationship of fatigue strength to life of notched and unnotched specimens in rotating beam tests. Finch[36] *on alloy steel*

* Any effects of wall thickness on thermal stresses under rapidly changing temperature conditions must also be considered if these are developed a large number of times during the predicted life since they may be accentuated by increasing the wall thickness.

ceived general acceptance by engineers. Hence service tests and laboratory tests of typical components are often resorted to in studying the efficiency of design, or the effect of fabrication methods, in order to obtain optimum proportioning.

INFLUENCE OF STATE OF STRESS ON FATIGUE STRENGTH

The circumferential tension in the shell of a cylindrical vessel subjected to internal gas pressure is normally twice the longitudinal tension. In other zones of the vessel, conditions approaching equal biaxial tensile stresses may be found. In the neighborhood of knuckles, brackets or reinforced openings, localized stresses with different degrees of biaxiality and differences in stress gradients may be encountered. It is unfortunate that fatigue test data on properties of material under biaxial stress conditions are incomplete or inadequate for design of full-sized members. Extensive data from combined bending and torsion experiments of small specimens have been published by Gough.[17] Here again, however, most of the results are analyzed on the basis of fatigue strengths for millions of cycles of stress, and may be utilized only qualitatively in predicting the limited-life fatigue strengths of pressure vessels.

Several investigators have tried to correlate stress states for fatigue fracture with theories of failure developed to express criteria for initiation of plastic deformation in metals subjected to static loading. No general correlations seem completely satisfactory for expressing the trends of fatigue data in terms of concepts such as the maximum strain theory, maximum shearing stress theory, etc.* Perhaps the best experimental correlations for *ductile* metals are obtained with the distortion energy or with shear stress criteria somewhat as indicated in Fig. 8. These theories are based on assumptions of homogeneous isotropic material, whereas it may be of importance to consider the anisotropy of forged or rolled metals when appraising the effects of stress raisers in a biaxial tensile stress field.[43] Findley[18] after appraising different theories on the basis of combined bending and torsion fatigue data suggests that a more thorough study of the influence of anisotropy on fatigue under combined stress is needed. He finds that the maximum shear stress theory when corrected for anisotropy may fit experimental data about as well as other theories. Ransom[16] also suggests that anisotropy is a primary factor; he finds the ratio of transverse to longitudinal fatigue strength to vary from 0.52 to 0.86 depending upon the melting practice used in producing the steel.

If the maximum shear stress theory were a valid criterion for failure, then the presence of biaxial tensile stresses in a thin-walled vessel would hardly be more serious from the viewpoint of initiating progressive fracture than the same maximum stress in a simple tension specimen. This seems to be borne out by experience in that thin-walled vessels seldom fail in fatigue. The maximum shear stress would be one-half the *algebraic* difference between the circumferential tensile stress in the shell and the internal pressure (the pressure would be considered a compressive or negative stress).

In thin-walled vessels the internal pressure is small compared with the magnitude of the stresses developed in the shell and can generally be neglected for practical purposes. For thick-walled vessels, however, the internal pressures may be very large and thus play an important part in reducing the allowable circumferential tension that may be developed in the shell. However in almost any zone of the vessel the notches, welded attachments and other abrupt details develop the peak stresses that are capable of nucleating fatigue failure and of controlling initial orientation of cracks.

EFFECT OF TEMPERATURE ON FATIGUE STRENGTH

It is difficult to cover in detail the various effects of the entire range of high and low temperatures encountered in different types of vessels. However, extensive test data indicate that depressing the temperature in laboratory fatigue tests has the effect of *increasing* the fatigue strength of either notched or unnotched specimens;[35] this is true for either ferrous or nonferrous metals. Hence as far as *fatigue* durability is concerned, any vessel that is safe for operation at room temperature is safe for operation at any lower temperatures encountered. This is contrary to the usual concepts of those familiar with the marked decrease in impact strength observed for certain steels at low temperatures.

Since many vessels operate at elevated temperatures it is important to consider the effects of medium and high temperatures (that is, those temperatures at which creep begins to become an important design factor) on the fatigue strength and notch-sensitivity of metals. Under these conditions, the criteria governing the design become more complex since the phenomena that limit the usefulness of the member involve a mixture of creep which is a "time-dependent" action, and fatigue fracture, which is a "cycle-dependent" phenomenon. Fracture at high temperature may result from either creep or fatigue or some combination of the two. Above certain temperatures, repeated stressing cannot be imposed without the simultaneous occurrence of creep. Thus even under cyclic loading, creep may be preliminarily responsible for the final failure. At moderately elevated temperatures (below the range in which creep becomes predominant), the fatigue properties of most steels are not appreciably lower than at room temperature. At extremely high temperatures for which creep becomes the primary consideration, the presence of appreciable amounts of alternating cyclic loading may have but little influence on the total *time* to cause fracture of the vessel. However over an intermediate range of temperatures (in which repeated stressing and continuing inelastic deformation in the form of creep combine to govern the phenomena of failure) the complex behavior is not predictable by the superposition of the data from separate creep tests and fatigue tests. For example, if the cyclic frequency of the fluctuating load is relatively low, the time to produce fracture may be quite long; hence, considerable time is available for damage by creep, and failure occurs under fewer cycles of stress than might be observed with a high frequency of the alternating load. Furthermore the longer time of operation may markedly alter the strength characteristics of the material by precipitation hardening, aging, or other structural changes that are stimulated by the presence of high temperature.

From the fatigue viewpoint, the intermediate range of temperatures (just below the level at which creep becomes severe) is most important and is the range for which few design data are available. At the highest temperatures it seems probable that satisfactory vessel designs can be evolved on the basis of creep as the sole criterion of failure (unless extremely large ranges of stress are involved in the service condition and these are applied with fairly high cyclic frequency).

Some of the effects of cyclic frequency and temperature on the fatigue strength of a low-carbon steel at 1200° F are shown in Fig. 9. It will be observed that for these conditions of testing, an ordinary static stress-rupture diagram has about the same slope and falls just slightly above the majority of the fatigue test data when the results are plotted in terms of *hours of operation*. However in tests of an 18Cr–8Ni steel at 1200° F., specimens run at 200 rpm withstood a *greater* number

* The details of these various theories are explained in most standard texts on Strength of Materials. For example, see references 18, 47 or 48 listed at the end of this paper.

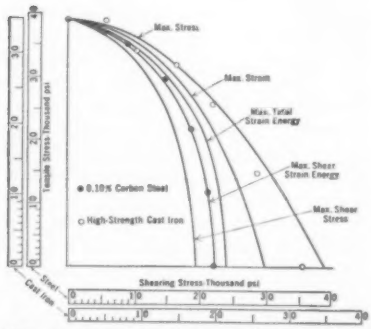


Fig. 8 Combined stress fatigue data

Ordinate and abscissa of any point show a combination of shearing stress and tensile stress amplitudes which cause failure. Gough[1]

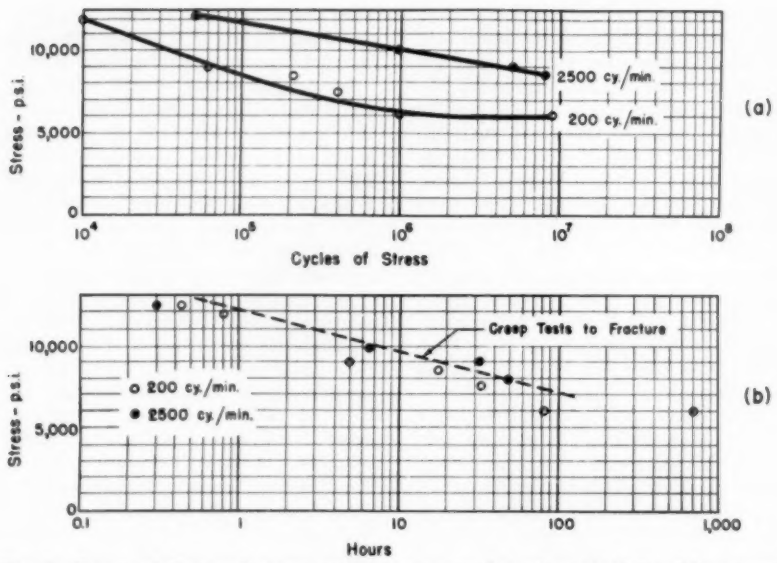


Fig. 9 Reversed flexure fatigue tests of structural steel at 1200° F. Moore and Alleman[15]

of cycles and showed a higher endurance limit than those tested at 2500 rpm.[41] This reversal of the time effect is an indication that a change in the austenitic microstructure increased the fatigue resistance of the metal during the longer time involved in the slower tests.

As for the ranges in which elevated temperature becomes important, typical data for a 12% Cr steel are shown in Fig. 10; the fatigue curves at elevated temperature do not become horizontal as is the case at room temperature. Ordinary carbon and low-alloy steels show a drastic drop in fatigue strength between 800 and 1000° F, but little significant change between room temperature and 700° F.[22, 23]

In general, the fatigue behavior of steels is not markedly affected by moderate heating above room temperature; the endurance limit might, therefore, be expected to vary in approximately the same manner as the static tensile strength until those temperatures are approached at which creep becomes a design factor.

For conditions of high temperature and mean stress at which *creep* becomes pronounced, the superposition of alternating stress of small amplitude does not materially reduce the life to fracture. Several studies indicate data of the type shown in Fig. 11, in which the rupture stresses for 200-hr life were not appreciably affected by superposition of cyclic stress.

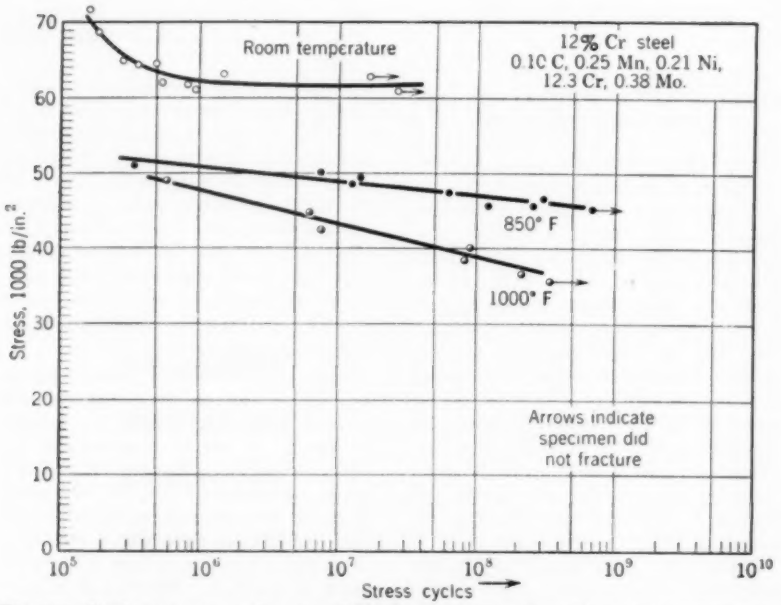


Fig. 10 Fatigue test results for 12% Cr steel as a function of temperature. Peterson[2]

For example, at 1350° F, rupture occurred under a *steady* mean stress of 29,000 psi; the allowable mean stress was reduced by only 4000 psi (to 25,000 psi) by superposition of an alternating stress whose amplitude was 17,000 psi. An even smaller fatigue effect was observed at 1500° F. However the superposition of alternating stress does tend to reduce the ductility displayed and, in some cases, may stimulate the rate of creep deformation observed.

The fatigue severity of a stress raiser is not necessarily alleviated by the creep that may occur at high temperature. Jones and Wilkes[24] found that at 1200° F the notch-sensitivity of high-temperature alloys in reversed bending was practically the same as that at room temperature. The influence of a given notch depended somewhat on how it was produced. Severely ground notches reduced the fatigue strength at room temperature by a factor of 5.0 whereas at 1200° F, the strength was reduced by a factor of only 2.4. Nevertheless when the same shape notch was cut by a lathe tool, the strength was reduced by factors of 1.8 at room temperature and 2.0 at 1200° F. The authors attributed these differences to residual stresses caused by the method of manufacture and their partial relief at elevated temperatures. It is important to note that the reduction in fatigue strength due to a stress raiser at high temperature was comparable to that obtained for ordinary steels at room temperature. The superposition of a high mean stress may develop creep to redistribute the stresses at the notch but may not be helpful in reducing the effect of the alternating component of stress superimposed by the fluctuation of loading.

In the presence of elevated temperature, therefore, the following additional factors must be given consideration: (*a*) the frequency of repetition of the stress cycle, (*b*) the metallurgical instability of metals at high temperature, (*c*) the pronounced influence of surface effects such as erosion, oxidation or chemical changes and (*d*) the accentuation of "time-dependent" creep caused by superposition of a steady stress.

In addition to the alteration in material properties at elevated temperatures, the problems of stress determination frequently become more complex because of the existence of thermal gradients and cyclic temperature variations. A steady thermal gradient will superpose a steady thermal stress that must be considered as a portion of the mean stress (Fig. 5) that will affect the allowable cyclic variation in stress. Furthermore, frequent cyclic variations of temperature may occur in localized zones; for example, White[8] describes fatigue failures in a boiler drum attributable to cyclic stresses due to temperature variations in the shell at the feed water inlet. In instances of this nature local design details become of extreme importance in limiting the service performance of the vessel.

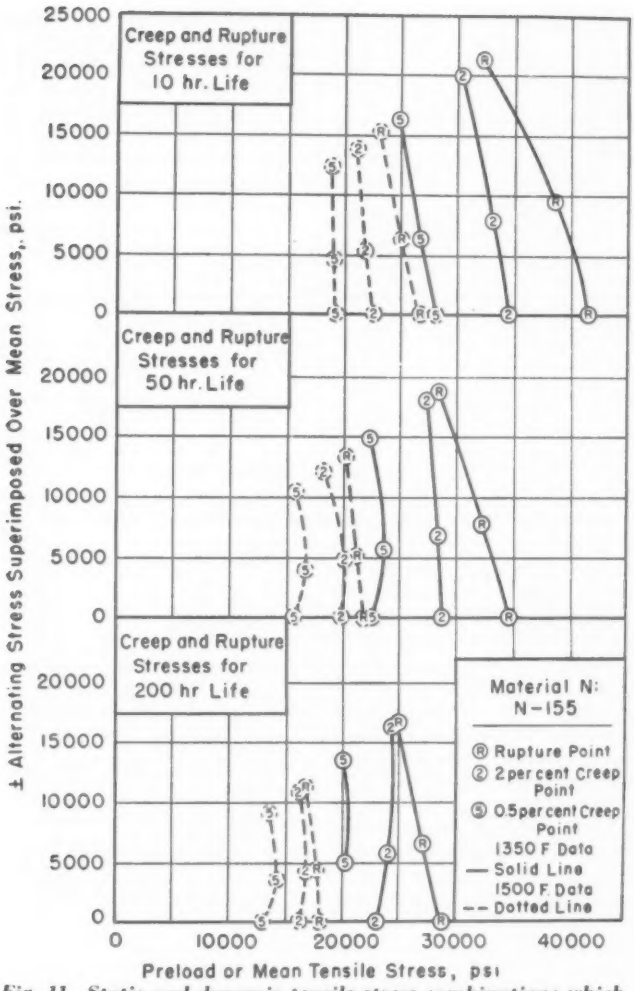

Creep and Rupture Stresses for 10 hr. Life
Creep and Rupture Stresses for 50 hr. Life
Creep and Rupture Stresses for 200 hr Life
± Alternating Stress Superimposed Over Mean Stress, psi.
Preload or Mean Tensile Stress, psi
Material N: N-155
® Rupture Point
② 2 per cent Creep Point
⑤ 0.5 per cent Creep Point
1350 F Data
— Solid Line
1500 F Data
-- Dotted Line

Fig. 11 Static and dynamic tensile stress combinations which cause rupture, 2 and 0.5% creep in 10, 50 and 200 hr at 1500 and 1350° F for N-155. Lazan[19]

WELDING EFFECTS

The extensive use of fusion welding in the manufacture of pressure vessels makes it important to consider any alterations in fatigue behavior caused by the weld metal or by the development of heat-affected zones and residual stresses set up by the processing. Wide variations in fatigue strength can result from poor welding; high strength is dependent upon soundness, proper fusion and freedom from inherent defects. The variety of welding procedures, types of weld details and variables involved during the welding operation may thus critically alter fatigue strength. The principal dangers to the strength of a pressure vessel that may be caused by welding are the possible presence of excessive porosity, lack of root penetration, cracking or cold shuts (weld metal deposited without complete fusion to the previously deposited weld metal or the base plate). These defects might be regarded as initial cracks in the structure, and hence are potential nuclei for fatigue failures. In high-class pressure vessel construction, however, under standardized welding procedures, and where careful inspection including radiographing of welds is included, there seems little reason to suspect that a fusion welded seam should of itself be particularly harmful.

Valuable data on the strength of welded plate with various kinds of electrodes and welding sequence have been obtained from laboratory experiments on $^1/_2$- to $^7/_8$-in. plate in axial load tests by Wilson and coworkers.[29-34] They found, for example, that specimens from which the reinforcement had been machined flush with the base plate on both sides had approximately the same fatigue strength as plates without welds but with the mill scale on. With surfaces polished, the fatigue strength was somewhat greater than that of specimens with mill scale but considerably lower than that of small round machined and polished laboratory specimens. They attributed this latter difference primarily to a "size effect." Stress relieving was not found to affect the fatigue strength markedly for butt welds in flat plate. However, this conclusion may not be applicable to vessels in which the locked-up stresses caused by welding may cause deleterious interaction between the various seams in the vessel (such as the "framing stresses" in ship construction). However, unless accompanied by metallurgical changes, the principal influence of a residual stress is to superpose a mean stress on the material in addition to that accompanying the loading. The data of Fig. 5 suggest that the fluctuating loads for failure are reduced if severe tensile residual stresses are present.

It is encouraging to find in Wilson's tests that the fatigue strength corresponding to failure at 2 million repetitions of stress (in which the stress varied from tension to tension one-half as great) exceeded the yield point of the material. Similarly, for specimens in the as-welded condition (for a cycle in which the stress varied from zero to a maximum tension) values of the fatigue strength were 33,100 psi for failure at 100,000 cycles, and 22,500 psi for failure at 2 million cycles. These values were for a carbon steel plate whose tensile strength was 59,000 to 63,500 psi and whose yield point was approximately 33,000 psi. Thus the yield point of the material may be exceeded for a large number of cycles of stress before failure develops.

Inspection by X-ray and radiograph ratings are important in eliminating major defects in welded seams but are not infallible in detecting all small surface defects that might prove damaging in fatigue. Wilson found no direct correlation between radiograph rating and the fatigue strength rating. This does not necessarily mean flaws shown by radiograph are not necessarily injurious, but rather that the stress-raising effects of lack of fusion or of the abrupt step at the edge of the reinforcing bead were more injurious than some of the flaws shown by the radiograph. As a further emphasis of the difference of behavior under static loading as compared with fatigue, it is interesting to note that grinding off the reinforcement of butt weld beads to make the weld faces flush with the base plate may reduce the static strength slightly for certain steels (as much as 10%) whereas this increased the fatigue strength of butt-welded carbon plates by as much as 30% in some instances. In general, the fatigue life of welded components is improved by:

(*a*) Grinding butt welds flush and smooth.
(*b*) Avoiding lap joints and aligning parts to avoid secondary bending.
(*c*) Providing gradual transitions in joining plates of different thickness.
(*d*) Streamlining fillet joints by elongating fillet or smooth grinding a gradual transition section.

(*e*) Avoiding high shrinkage stresses by planned sequence of welding.

(*f*) Eliminating undercuts, brackets, misalignments or openings at locations of high stress.

MISCELLANEOUS CONSIDERATIONS

Values of fatigue strength or of fatigue life must be regarded as statistical in nature; they are susceptible to rather wide variations depending upon chance effects in sampling, anisotropy and variability of material, and differences in testing technique. It is mainly because of these statistical aspects that it has been impossible to develop simple quantitative design procedures and to be more specific in stating fatigue "know-how" in papers such as this. In obtaining data for design, it would be desirable to test large numbers of samples and analyze the data in terms of the probability of a member exceeding a given life or given strength.[43] This is usually not economically feasible for full-sized members such as pressure vessels, but emphasizes the need for careful and conservative interpretation of data from random experiments at arbitrarily selected stress levels. The statistical spread in fatigue life for different probabilities of failure is illustrated in Fig. 12; it is not unusual to encounter ratios of 10 to 1 in fatigue life of duplicate specimens even under carefully controlled laboratory conditions.[44]

On the other hand, large members (particularly those with stress-raisers) usually exhibit less scatter than small laboratory specimens. Furthermore, small decreases in the peak stress ranges are accompanied by large increases in fatigue life; since the reverse is also true a single severe notch may limit the fatigue life. Thus if the maximum stresses are controlled by eliminating the severe stress raisers, the problem becomes less discouraging and the question of the exact fatigue life is of more academic than of real interest.

The question of effect of cyclic frequency and influence of rest periods of no loading during the operation of a pressure vessel is often raised when considerations are given to fatigue failure. For normal conditions of operation in which high temperatures and corrosive conditions are not encountered, the frequency of loading has little influence on the number of cycles required for fracture. However at high stress levels (exceeding the yield strength of the metal), continuing plastic deformations may occur even at room temperature; thus low frequency and long sustained loadings may reduce the number of cycles of loading for failure. At higher rates of loading, small laboratory specimens have shown little influence of frequency on fatigue limit up to as high as 30,000 cpm for operation at ordinary temperatures.[30] However the frequency is important at *high temperatures;* for the slow cyclic frequencies normally encountered in pressure vessels, the life may be primarily governed by creep effects. Periodic rest periods during repeated stressing have been found to have little influence on the fatigue strength of welded plate.[30] Other studies suggest that perhaps any effects of rest periods on steels may be beneficial rather than harmful.[21] The added time involved in the rest periods may allow a strain-aging to occur that strengthens a low-carbon steel making it more resistant to the development or progression of fatigue damage. In general (except for very high temperature operation or presence of corrosive environment), intermittent periods of no load during the life of a vessel should have no harmful influence on its resistance to fatigue failure.

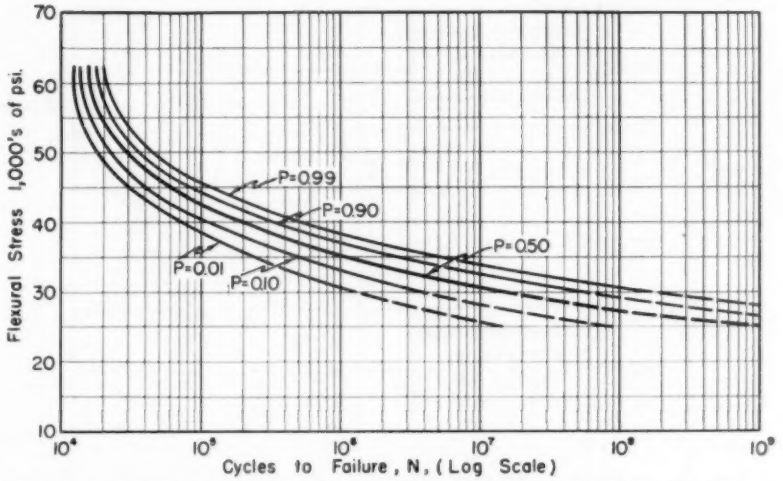


Fig. 12 Composite S–N curves for various probabilities of failure, P. Data of Sinclair and Dolan[41] for small unnotched specimens of aluminum alloy 75S-T

One must be skeptical about transferring quantitatively the results of fatigue tests of laboratory specimens to full-size structures such as pressure vessels. Limited-life fatigue testing can be highly misleading; the same metal tested in two different kinds of machines may exhibit different life to failure at the same general stress level. Similarly, two different metals may exhibit a crossing of the *S–N* curves as shown in Fig. 13. In this case entirely different conclusions would be drawn regarding the relative fatigue life of these steels when compared at high strain and again at low strain; thus "overloads" used to shorten the duration of a test may not always be reliable in predicting the relative performance of structures at the lower stresses expected in service. Laboratory test data are useful in qualitatively indicating the relative effects of notches, heat treatments, surface finish, etc., but other factors that enter into the fabrication or construction of large members (such as the presence of segregation, decarburization, arc strikes and defects arising from processing in the shop such as cold forming, shearing, gouging, stamping, etc.) may be the tremendous trifles that govern the fatigue strength of the finished structure. Any inadvertent surface blemishes should be regarded as potential nuclei for progressive fracture when they are present in critical locations that are subjected to large stress fluctuations.

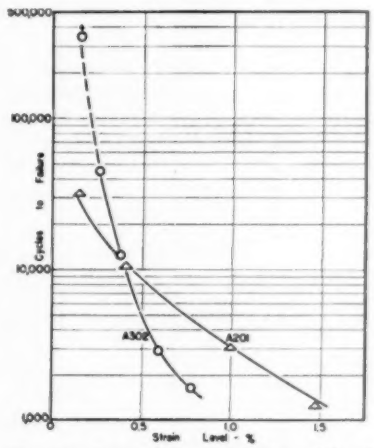


Fig. 13 Comparison of fatigue life of two steels under biaxial plastic strains

Note crossing of the curves which indicates that different conclusions would be drawn regarding their relative fatigue behavior at high strains from those at low strains (Gross, Tsang, Stout[37]). The yield point for these steels was about 38,000 psi for the A201 and about 62,400 psi for the A302 steel.

CONCLUSIONS

In general, a vessel that is safe from the viewpoint of static load design criteria (and which is not to be subjected to an excessively large number of cycles of loading) would probably have adequate resistance to fatigue fracture if all stress raisers were eliminated. This is difficult if not impossible because of the many attachments, openings and appurtenances that are frequently incorporated to meet a functional need. Nevertheless, in view of the seriousness of the damage that results from progressive fracture, every

effort should be made to eliminate needless severe stress raisers and to give careful consideration to the fatigue behavior of many types of pressure vessels. Better information is needed regarding the behavior of pressure vessel steels (particularly for the newer low-alloy high-strength types) in the finite life fatigue range, and their susceptibility to stress raisers of the types encountered in pressure vessels.

Bibliography

1. Staff of Battelle Memorial Institute, *Prevention of the Failure of Metals Under Repeated Stress*, John Wiley & Sons, New York (1941).
2. Murray, W. M., Editor, *Fatigue and Fracture of Metals*, John Wiley & Sons, New York (1952).
3. Symposium held at the University of Melbourne, Australia, "The Failure of Metals by Fatigue," University of Melbourne Press (1947), 505 pp.
4. Peterson, R. E., "Review of the Fatigue of Materials Field," *Appl. Mech. Revs.*, **5**, 1–3 (January 1952).
5. Kooistra, L. F., and Blaser, R. U., "Experimental Technique in Pressure-Vessel Testing," *Trans. ASME*, **72**, 579–589 (1950).
6. Schoessow, G. J., and Brooks, E. A., "Analysis of Experimental Data Regarding Certain Design Features of Pressure Vessels," *Trans. Am. Soc. Mech. Engrs.*, **72**, 567 (1950).
7. Anonymous, "Pulsating-Pressure Testing Plant for Pressure Vessels," *Engineering*, **170**, No. 4425, 384 (Nov. 17, 1950).
8. White, A. E., "Changes in a High Pressure Drum to Eliminate Recurrence of Cracks Due to Corrosion Fatigue," *Trans. Am. Soc. Mech. Engrs.*, **61**, 507 (1939).
9. Moore, H. F., "Tests of the Resistance to Repeated Pressure of Forged, Riveted, and Welded Boiler Steels," *Ibid.* (Fuels and Steam Power Section) (January-April 1931).
10. Orowan, E., "Stress Concentrations in Steel Under Cyclic Load," THE WELDING JOURNAL, **31** (6), Research Suppl., 273-s to 282-s (1952).
11. Copson, H. R., "The Influence of Corrosion on the Cracking of Pressure Vessels," *Ibid.*, **32** (2), Research Suppl., 75-s (1953).
12. Collins, W. L., and Dolan, T. J., "Physical Properties of Four Low-Alloy High-Strength Steels," *Proc. ASTM*, **38**, Part II, 157–175 (1938).
13. Thielsch, Helmut, *Thermal Fatigue and Thermal Shock*, Welding Research Committee Bull. Ser., No. 10 (April 1952).
14. Blaser, R. U., Tucker, J. T., and Kooistra, L. F., "Biaxial Fatigue Tests on Flat-Plate Specimens," THE WELDING JOURNAL, **31** (3), Research Suppl., 161-s (1952).
15. Yen, C. S., and Dolan, T. J., *A Critical Review of the Criteria for Notch-Sensitivity in Fatigue of Metals*," Bull. No. 398, Engrg. Expt. Sta. Univ. Ill. (1952).
16. Smith, James O., *The Effect of Range of Stress on the Fatigue Strength of Metals* Bull. No. 334, *Ibid.* (1942).
17. Gough, H. J., "Engineering Steels Under Combined Cyclic and Static Stresses," *Inst. Mech. Engrs., Proc.*, **160**, No. 4, 417–440 (1949).
18. Findley, W. N., "Fatigue of 76S-T61 Aluminum Alloy Under Combined Bending and Torsion," *Proc. ASTM*, **52**, 818 (1952).
19. Lazan, B. J., "Dynamic Creep and Rupture Properties of Temperature-Resistant Materials Under Tensile Fatigue Stress," *Ibid.*, **49**, 757 (1949).
20. Krouse, G. N., "A High Speed Fatigue Testing Machine and Some Tests of Speed Effect on Endurance Limit," *Ibid.*, **34**, Part II, 156 (1934).
21. Sinclair, G. M., "An Investigation of the Coaxing Effect in Fatigue of Metals," *ASTM, Ibid.* **52**, 743 (1952).
22. Dolan, T. J., "How Can We Appraise Metals for High Temperature Service?" *Metal Progress*, **61**, 55 (March 1952).
23. Dolan, T. J., "Problems of Metallic Fatigue at High Temperature," *Ibid.*, **61**, 97 (April 1952).
24. Jones, W. E., and Wilkes, G. B., Jr., "The Effect of Various Treatments on the Fatigue Strength of Notched S-816 and Timken 16–25–6 Alloys at Elevated Temperatures," *Proc. ASTM*, **50**, 744 (1950).
25. Markl, A. R. C., "Fatigue Tests of Welding Elbow and Double-Mitre Bends," *Trans. Am. Soc. Mech. Engrs.*, **69**, 869 (1947).
26. Tör, S. S., Ruzek, J. M., and Stout, R. D., "Repeated Load Tests of Welded and Prestrained Steels," THE WELDING JOURNAL, **31** (5), Research Suppl., 238-s (1952).
27. Gross, J. H., Tsang, S., and Stout, R. D., "Factors Affecting the Resistance of Pressure Vessel Steels to Repeated Overloading," *Ibid.*, Research Suppl., XVIII (1), 23-s to 29-s (1953).
28. Soete, W., and Van Crombrugge, R., "Fatigue Strength of Welded Joints," *Ibid.*, **31** (2), Research Suppl., 100-s (1952).
29. Wilson, Wilbur M., and Burke, James L., "Rate of Propagation of Fatigue Cracks in 12-by ¾-In. Steel Plates with Severe Geometrical Stress Raisers," *Ibid.*, Research Suppl., XIII (8), 405-s to 408-s (1948).
30. Committee F, "Effect of Periods of Rest on the Fatigue Strength of Welded Joints," Welding Research Committee of Engrg. Foundation, January 1941.
31. Committee on Fatigue Testing, "Fatigue Strength of Welded Butt Joints," THE WELDING JOURNAL, **29** (8), Research Suppl., 404-s (1950).
32. Wilson, W. M., Bruckner, W. H., Coombe, J. V., and Wilde, R. A., *Fatigue Tests of Welded Joints in Structural Steel Plates*, Bull. 327, Engrg. Exptl. Sta., Univ. Ill. (1941).
33. Wilson, W. M., Bruckner, W. H., and McCrackin, T. H., *Tests of Riveted and Welded Joints in Low-Alloy Structural Steels*, Bull. 337, *Ibid.* (1942).
34. Wilson, W. M., Bruckner, W. H., McCrackin, T. H., and Beede, H. C., *Fatigue Tests of Commercial Butt-Welds in Structural Steel Plates*, Bull. 344, *Ibid.* (1943).
35. Zambrow, J. L., and Fontana, M. G., "Mechanical Properties Including Fatigue, of Aircraft Alloys at Very Low Temperatures," *Trans., Am. Soc. Metals*, **41**, 480 (1949). See also: Spretnak, J. W., Fontana, M. G., and Brooks, H. E., "Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25°C and −196°C," *Ibid.*, **43**, 547–570 (1951).
36. Finch, W. G., "A Study of Steels in the Finite Region of the S-N Curve," *Proc., ASTM*, **52**, 759 (1952).
37. Weisman, M. H., and Caplan, M. H., "The Fatigue Strength of Steel Through the Range from ½ to 30,000 Cycles of Stress," *Ibid.*, **50**, 649 (1950).
38. Neuber, H., *Theory of Notch Stress—Principles for Exact Stress Calculation*, J. W. Edwards, Inc., Ann Arbor, Mich. (1946).
39. Morkovin, D., and Moore, H. F., "Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel," *Proc., ASTM*, **44**, 137 (1944).
40. Bowman, C. E., and Dolan, T. J., "Biaxial Fatigue Properties of Pressure Vessel Steels," THE WELDING JOURNAL, **32** (11), Research Suppl., 529-s (1953).
41. Cross, H. C., "High Temperature Tensile, Creep, and Fatigue of Cast and Wrought, High and Low Carbon 18 Cr-8 Ni Steel from Split Heats," *Trans., Am. Soc. Mech. Engrs.*, **56**, 533 (1934).
42. Karry, R. W., and Dolan, T. J., "Influence of Grain Size on Fatigue Notch-Sensitivity," ASTM Preprint No. 72 (June 1953).
43. "Fatigue, with Emphasis on Statistical Approach II," Spec. Tech. Publ. 137, *ASTM* (January 1953).
44. Sinclair, G. M., and Dolan, T. J., "Effect of Stress Amplitude on Statistical Variability in Fatigue Life of 75S-T6 Aluminum Alloy," *Trans., Am. Soc. Mech. Engrs.*, **75**, 867 (1953).
45. Moore, H. F., and Alleman, N. J., "Progress Report on Fatigue Tests of Low Carbon Steels at Elevated Temperatures," *Proc., ASTM* **31**, Part I, 114 (1931).
46. Ransom, J. T., "Effect of Inclusions on the Fatigue Strength of 4340 Steels," Am. Soc. Metals, Preprint (October 1953).
47. Marin, J., *Strength of Materials*, Macmillan Co., New York (1948).
48. Seely, F. B., and Smith, J. O., *Advanced Mechanics of Materials* John Wiley & Sons, New York (1952).

Fatigue Tests of Steel Specimens Prepared for Metallizing

Laboratory tests show the extent to which preparation for metallizing lowers the fatigue strength of steel shafts

by R. C. Miller, Jr. and A. W. Brunot

Synopsis

The effect of several surface preparation procedures on the fatigue resistance of steel shafts was determined. The rough threading method was found to be the least damaging of the methods studied with grooving and roughening closely following. Electrode roughening and metallic spray bonding were found to be less desirable from the standpoint of strength reduction of parts which are subject to fatigue stresses. Although rough threading showed a slight improvement in fatigue strength, grooving and roughening would be preferred in practice since it provides more consistent and higher deposit bond strength.

Two possible methods for improving the fatigue resistance of metallizing preparations were investigated: (1) shot peening and (2) enlarging the radii at the ends of the preparation undercut. Shot peening was found to be the more effective of the two proposed methods.

R. C. Miller, Jr., is a Welding Engineer and **A. W. Brunot** is Consulting Mechanical Engineer at the Thomson Laboratory, General Electric Co., W. Lynn, Mass.

Presented at the AWS National Spring Meeting, held in Buffalo, N.Y. May 4–7, 1954.

The discussion applies to only one shaft material, and broad generalizations should not be made without tests of other materials.

INTRODUCTION

THE metallizing gun has attained universal acceptance as a standard machine tool. It is being applied, more and more, in the manufacture of new equipment such as certain steam turbine shafts which are made corrosion resistant at packing fit areas. It has also retained an enviable reputation as a maintenance tool for reclaiming parts which are damaged in service by wear, corrosion or erosion. For the repair of such parts, suitable metallic coatings are sprayed onto those areas which are required to resist the particular damaging action. Metallizing, in many cases, may be performed on equipment which is in normal operating position, thus saving time and money which would otherwise be lost through disassembly and moving operations.

It is a generally accepted fact that an application of metallizing can be no better than its bond. In the absence of fusion, such as that which is associated with arc welding, metallizing depends, to a very great extent, upon the use of special surface roughening techniques to provide mechanical bonding or keying of the deposit metal to its base. Consequently, considerable importance must be placed upon the surface preparation of a metallized area.

In the metallizing of machinery components, it is customary to perform three basic steps—preparing the surface, spraying the deposit and finishing the deposit metal to final dimensions. When considering the process for a new application, the selection of the type of deposit metal and the techniques by which it is to be deposited and finish-machined are generally only of moderate concern since metallizing materials and methods for depositing and finishing them have been fairly well established. Surface preparation procedures, on the other hand, are arbitrary, and many different methods are used. Factors which ordinarily determine the appropriate method would, no doubt, include operating conditions to be imposed on the part in service, base metal, process costs and availability of equipment. At the same time, it must be appreciated that, no matter what method is selected, the endurance properties of the part will be adversely affected by the preparation procedure. Fatigue strength may well be a factor, particularly in view of present-day designs which specify higher-than-ever operating speeds. Consequently, this investigation was undertaken to compare fatigue properties resulting from the application of several well-known surface roughness preparation methods, and to consider the possibilities of improving them.

PREPARING AND TESTING THE SPECIMENS

The purpose of the tests described here was to determine the resistance of a steel shaft prepared for metallizing to repeated cycles of stress. The test specimens and the fatigue testing machine were used in such a manner as to simulate the loading and bending conditions of a steam turbine shaft in service. The test, then, consisted of submitting the specimens to cycles of completely reversed stress of various magnitudes and counting the number of cycles required to cause a fracture in the specimen, or determining that the specimen would withstand a very large number of cycles without fracture. From the test data, a plot of the applied stress vs. the number of cycles resulted in a diagram commonly referred to as the S-N or stress-frequency curve. From curves of this type, it is known that there is a stress level for each test condition below which the specimen will withstand a very large number of cycles without fracture taking place. This leveling portion of the curve represents the endurance limit referred to as the basis of the fatigue test results obtained in this investigation.

The base material selected for investigation was AISI-4142 chromium-molybdenum steel bar, hot-rolled, heat-treated, machine-straightened and stress-relief annealed. Its nominal chemical composition and mechanical properties are listed in Table 1.

Table 1—Data Pertinent to Specimen Base Material—AISI 4142

Chemical composition	
Carbon, %	0.40–0.45
Manganese, %	0.75–1.00
Molybdenum, %	0.15–0.25
Chromium, %	0.80–1.10
Silicon, %	0.20–0.35
Phosphorus, %, max	0.04
Sulphur, %, max	0.04
Mechanical properties	
Tensile strength, psi	105,000
Yield strength (0.02% offset), psi	80,000
Elongation in 2 in., %, min	20
Reduction of area, %, min	50

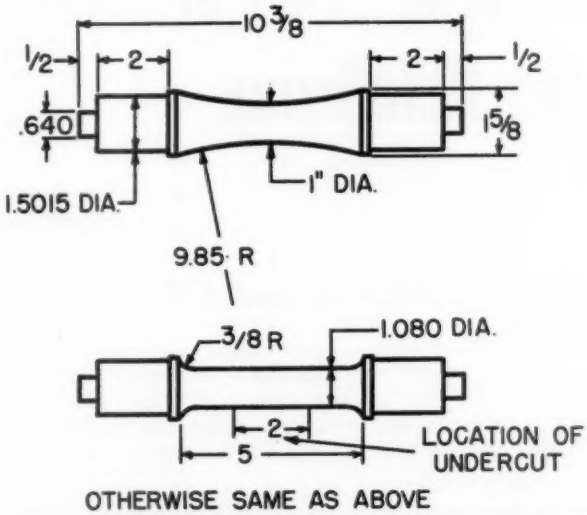


Fig. 1 Dimensions of fatigue test pieces; smooth polished specimen (top) and preparation method specimen (bottom)

Fatigue specimens were machined from bar stock to the dimensions shown in Fig. 1. The upper specimen is a standard bar for a Sonntag SR-10 fatigue machine, and was used to represent the fatigue conditions of a shaft without any preparation for metallizing. The lower specimen represents the basic shaft which was further modified by the various preparation procedures. (All fatigue tests were conducted at 3475 rpm in the SR-10 fatigue machine.)

Undercutting was applied to the 2 in. length at the center of the simulated shaft specimens to a standard radial depth of 0.040 in. as shown in Fig 2. The standard undercut shown in the upper part of this figure is generally used as the basis of further preparation. The 0.015 in. radius at the end of the undercut appears to be the critical point. The enlarged radius, shown in the lower part of Fig. 2, was used to determine the effect of changing this corner radius on the endurance limit of the shaft.

The standard undercut (see Fig. 3) provided an endurance limit of 28,000 psi as compared to the endurance limit of the smooth polished specimen of 58,000 psi. The enlarged end radii of the special undercut were responsible for increasing the endurance limit from 28,000 to 33,000 psi, but shot peening the standard undercut radii raised the endurance limit to 36,000 psi. Shot peening, then, appears to be more effective than enlarging the undercut end radii in reducing the loss in endurance limit which results from undercutting. It is also desirable from a bond strength viewpoint since the standard undercut with the 15 degree side angle would be retained to provide bonding of the sprayed coating at the ends of the undercut. Shot peening was not applied to the special undercut since it would not provide suitable roughness in practice.

To determine the effect of additional preparation procedures on the endurance limit of the undercut shaft, the undercut portion was prepared by grooving and roughening, rough threading, metallic spray bonding and electrode roughening. In view of the relatively small improvement of the enlarged end radius of the special undercut, the additional preparations were all applied to the standard undercut with the exception of one trial of metallic spray bonding in the special undercut. Tests of these specimens provided fatigue data on shafts completely prepared for application of the sprayed metal.

The grooving and roughening procedure was applied

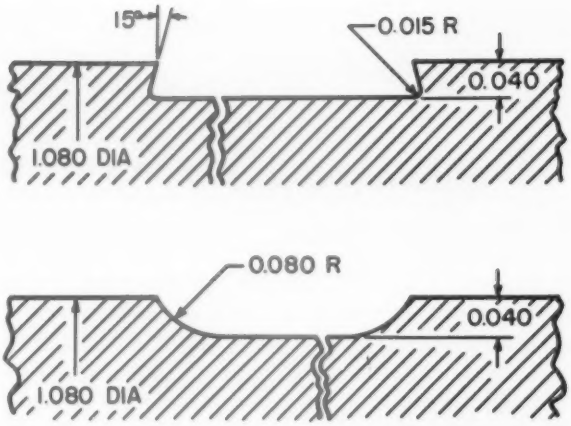


Fig. 2 Types of undercut applied to preparation method specimens; standard undercut (top) and special undercut (bottom)

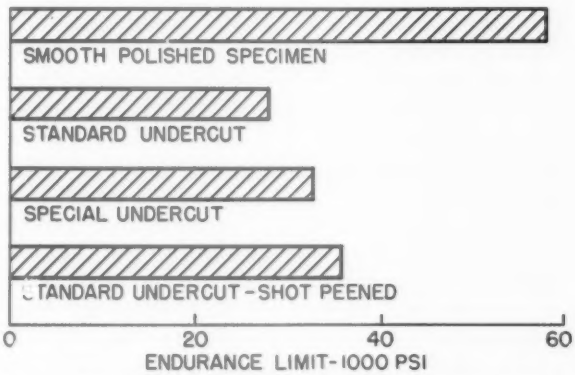


Fig. 3 Effect of undercutting on the endurance limit of the specimen

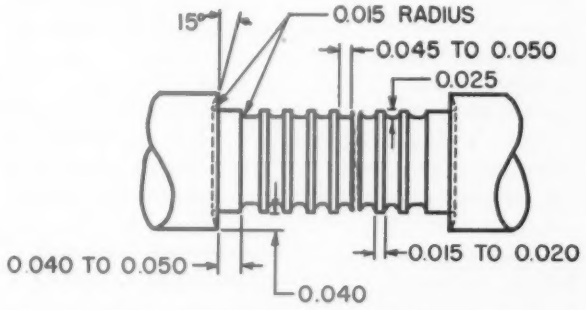


Fig. 4 Shaft grooving procedure for grooving and roughening preparation method

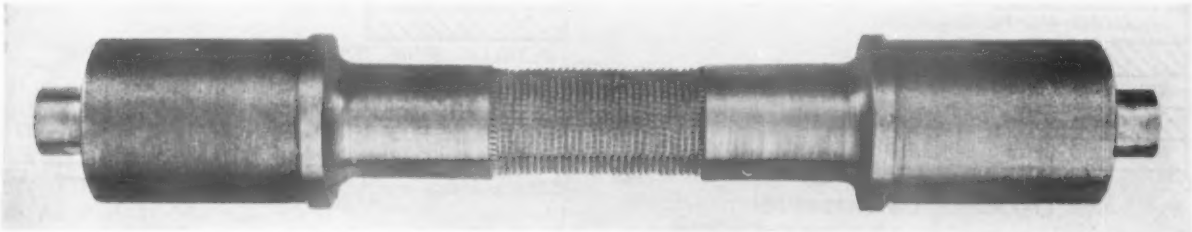


Fig. 5 Specimen prepared by standard grooving and roughening method

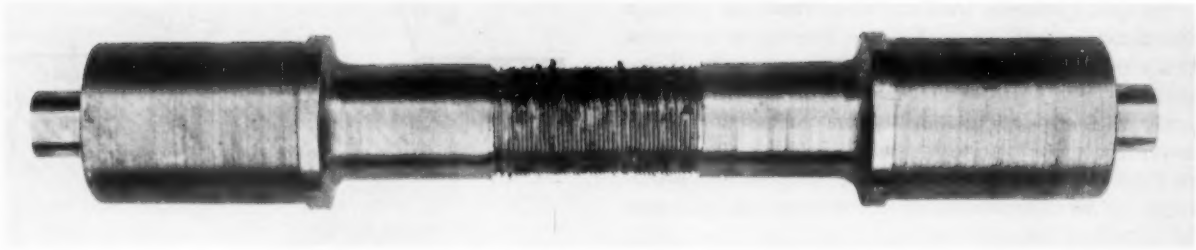


Fig. 6 Specimen with rough threading preparation method

by cutting annular grooves as shown in Fig. 4 and using a special rotary roughening tool to roughen and spread the areas between the grooves. A specimen prepared in this manner is shown in Fig. 5. This method is generally used for maximum deposit bond strength.

Rough threading was applied to the standard undercut by means of a threading tool in such a manner as to provide a tearing action on the sides of the thread. The nose angle of the tool is 60°, and the tool nose radius is 0.020 in. The depth of cut was 0.020 in. with a thread feed of 24 per inch. A specimen prepared by this method is shown in Fig. 6. Rough threading is widely used as a roughening procedure. It is economical and permits a good bond between the sprayed metal and the shaft.

Metallic spray bonding was introduced to the undercut by spraying a coating of molybdenum to a radial depth of 0.002 to 0.003 in. This metal has the property of bonding itself to a clean metallic surface when sprayed, and was included in this investigation as a possible method of roughening both the standard and special undercuts.

Electrode roughening was applied by depositing nickel from a welding electrode and covering the base of the undercut with small irregularly shaped weld particles. A special transformer was used to provide low voltage, and the electrode was passed over the undercut surface with a scratching motion. This method was included in order to compare with standard methods a roughening procedure which was known to lower endurance limit considerably, and to determine the effect of shot peening on a preparation method having low endurance strength. The operating conditions for shot peening are shown in Table 2.

Table 2—Operating Conditions for Shot Peening

Type of shot	Chilled iron, SAE No. S-110
Equipment	Standard manual cabinet, 5/8 in. suction nozzle, 9/32 in. air jet
Line air pressure	75 psi
Peening time	30 seconds on each radius plus 2 minutes on undercut base where applied
Almen "A" Specimen Arc Height	0.010 to 0.011 in.

TEST RESULTS OF COMPLETE PREPARATION METHODS

Endurance limit values were obtained for each of the complete preparation methods tested. For uniformity, the stress was calculated at the 1 in. diam of the undercut which was common to all specimens.

The results are shown graphically in Figs. 7, 8 and 9 and refer to specimens which contained metallizing surface roughness procedures only and no sprayed deposit metal. It was deemed desirable to segregate the effect of undercutting, and then to compare it with that of complete roughening methods. If the specimens containing the complete roughening methods had been sprayed, the direct comparison would then be rightfully questioned. As a matter of fact, specimens containing sprayed deposits were actually prepared and tested in parallel with specimens containing no deposit metal, and it was found that deposit metal

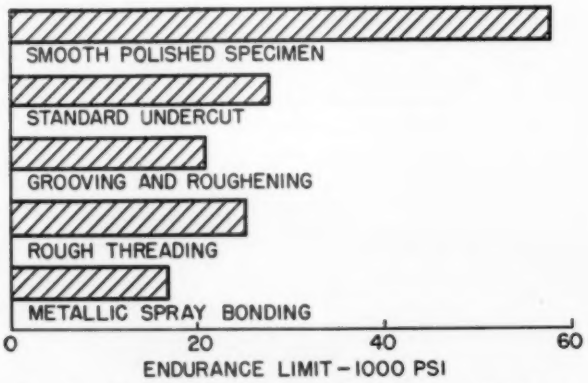


Fig. 7 Effect of standard preparation methods on endurance limit

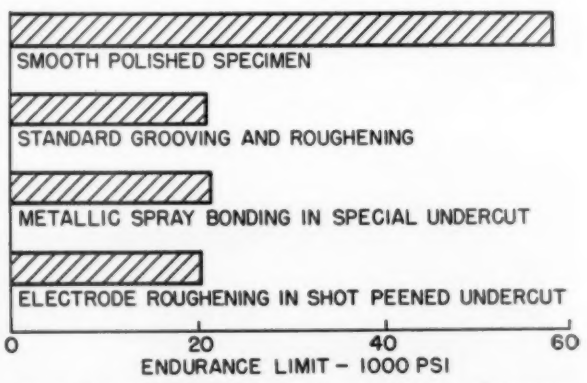


Fig. 8 Effect of special roughening methods on endurance limit

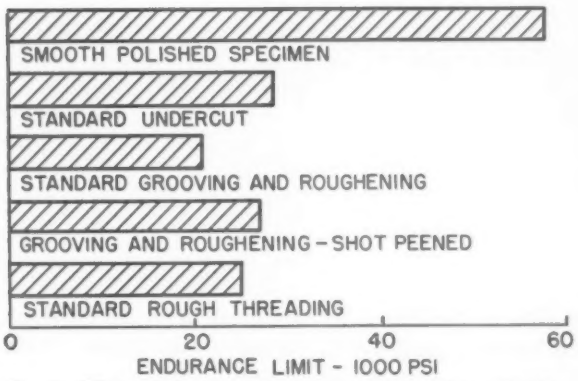


Fig. 9 Effect of shot peening on grooving and roughening preparation method

had no appreciable effect on endurance limit values or on the extent or locations of fatigue fracture.

Comparing the effect of standard preparation methods, including the standard undercut (see Fig. 7), rough threading caused a lowering of endurance limit from the smooth polished specimen value of 58,000 to 25,500 psi. The corresponding value for grooving and roughening was 21,000 psi and for metallic spray bonding, 17,000 psi. Since it was already known from previous tests that the endurance limit value as the result of electrode roughening is relatively low, it was not included in this group but rather as a special roughening method, since it was combined with the shot peened undercut.

The results of two special roughening methods are shown in Fig. 8. Metallic spray bonding in the special undercut and electrode roughening in the shot peened undercut provide no practical improvement over standard grooving and roughening which gives much higher bond strength. These results led to the conclusion that shot peening applied to the grooving and roughening preparation might provide endurance improvement without affecting the high deposit bond strength.

The effect of shot peening on the grooving and roughening method is shown in Fig. 9. The shot peening was applied after grooving and prior to roughening with the special rotary tool. The endurance limit was increased, as the result of shot peening, to 27,500 psi which is slightly higher than that of the rough threading method. When fatigue fracture occurred in the specimens prepared either by grooving and roughening or rough threading, it took place in the groove or thread adjacent to the undercut fillet. Shot peening over the entire undercut, fillets and grooves, did not change the location of the fracture of the grooved and roughened specimens. Since the highest stress concentration was in the roughened thread rather than in the undercut fillet, shot peening was not applied to the rough thread preparation.

High speed spin tests showed that shot peening can be applied as part of the grooving and roughening preparation procedure without lowering the metallizing bond strength. The tests were made on 4-in. diam shafts which contained metallized sections. After finish-machining the sprayed metal, a slot was cut axially over the entire length of the shaft, completely through the sprayed metal. The shaft was then rotated at increasing rotational speeds until fracture of the sprayed metal took place. In every case where shot peening had been applied, the rotational speed obtained at the first sign of failure was as high or higher than corresponding speeds of the sections which were not shot peened.

SUMMARY

Since only one shaft material was considered in this investigation, broad generalizations should not be made without tests of other materials. The above results do show that, where fatigue is a factor, the surface preparation for metallizing may have a damaging effect on endurance properties. Undercutting, in itself, causes a large proportion of the over-all effect primarily because of the radius at the ends of the undercut. Roughening procedures applied to the undercut further reduce the endurance limit of the shaft.

The standard high bond-strength preparations, grooving and roughening and rough threading, are also favorable from a fatigue standpoint. The slight advantage in fatigue strength of rough threading would not, in this case, justify its use in place of grooving and roughening since the latter method provides more consistent and higher deposit bond strength. Where maximum deposit bond strength is to be combined with high endurance limit, the grooving and roughening method with shot peening is the preferred method. Selecting the metallizing surface roughness procedure to provide maximum deposit bond strength is excellent practice whether fatigue is or is not a factor.

Correction

IN THE article "Evaluation of Superheater Materials for High-Temperature Steam" by Bela Ronay and W. E. Clautice, starting on page 199-s of the Supplement to the April 1954 issue of THE WELDING JOURNAL, the authors inadvertently omitted an acknowledgement that Joseph W. Hopkins, Jr., a member of the Welding Laboratory of the U. S. Naval Engineering Experiment Station constructed the scale models illustrating the above article.

In Tables 1, 2 and 3 the chemical symbol for vanadium is given incorrectly as Va instead of V.

Research of Welding Arc

Report on the studies of the characteristics of welding are including self-regulation; material; current; voltage; and electrode fall

by M. Ozawa and T. Morita

1. INTRODUCTION

IF YOU take an oscillogram of the arc current or voltage during welding with the automatic or hand welder, you will find ripples in the arc voltage in spite of the fact that the arc current is kept constant.

You will observe the ripples alone for the d-c source, while the ripples are superposed on the commercial frequency under the a-c source.

Up to the present, the above phenomenon has been simply reduced to the sputtering of the metal, or the influence of the electric source, and the effect of the automatic welder.

It seems, however, that there are problems which are not completely solved by the above explanations. For example, the period of the ripple is under $^1/_{100}$ sec while the response time of the automatic welder is as long as $^{17}/_{100}$ sec.

We postulate that there is an additional factor, namely, the self-regulation of the arc, and according to our theory, the sputtering of the metal should be included in this self-regulation.

The experimental results seem to be satisfactorily coincident with our consideration.

2. THE SELF-REGULATION OF THE ARC

Generally speaking, there are many theories about the arc, which is like our self-regulation. These are, for instance, Steenbeck's minimum power theory[3] on the arc column and the energy-balance theory of the cathode.

In reference to the welding arc, Müller[5] has investigated how the arc length corresponds to the oscillation of the electrode.

But his results are quite different from our ripple in question.

Now, when the arc is ignited between the plate and the electrode which is fed with constant speed, the arc is in steady-state.

If the arc is lengthened by some unknown reason, the melting speed of the electrode decreases and its tip has a tendency to go back to the previous position, i.e., the position in the steady-state. It may be considered that the sputtering of the metal decreases.

On the contrary, if the arc length becomes short, the melting speed of the electrode increases and its tip, too, tends to come back to the steady-state position. In this case, the sputtering of the metal may be considered to increase.

These phenomena are quite easily explained if the arc current varies in correspondence with the arc length; namely, when the arc becomes long, the arc voltage increases and the arc current decreases with decrease of the melting speed.

As the tip of the electrode has the speed equal to the difference of the melting and feed speed of the electrode, and besides the latter is higher than the former, it is natural that it has the tendency to go back to the same position.

As it is also true under the opposite condition, the tip of the electrode seems always to stay at the same position in steady-state.

These are, however, not new facts and as you know, will be explained as a simple phenomenon in physics, which, according to Müller,[5] seems to be reduced to the self-regulation of the arc.

However, the facts are not the same as the above. Even when the arc length changes, i.e., the ripple occurs, the arc current does not change.

Here, we must consider again the ripple from the viewpoint quite different from the above. If you say that the variation of the sputtering induces the ripple, why does the sputtering increase or decrease in spite of the constant current?

Thus, we should take the "self-regulation of the arc" into consideration.

As Fig. 1 illustrates, the electrode is fed with a constant velocity v, and the tip of the electrode retards with the melting speed u.

We will take as the origin the position of the tip in steady-state of the arc, and take as the x-axis the direction to the plate.

Let us consider how the position of the tip moves as time passes.

M. Ozawa and **T. Morita** are members of the Electrotechnical Laboratory of Japan.

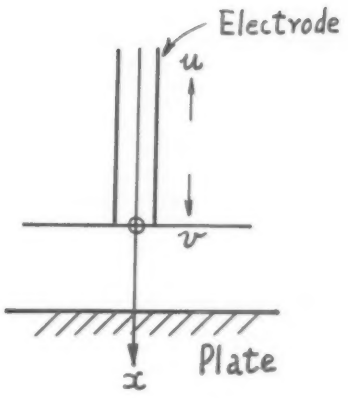


Figure 1

First of all, as an assumption, we will consider that the acceleration of the movement of the tip is proportional to the distance from the origin and its direction is always to the origin.

So,

$$-\dot{u} + \dot{v} = k^2 x \tag{1}$$

k = constant concerning the arc current and the material of the electrode.

According to the assumption, v is constant for time, and so, $\dot{v} = 0$. And eq 1 is reduced to:

$$-\dot{u} = k^2 x \tag{2}$$

If integrated,

$$u = c - k^2 \int x\, dx \tag{3}$$

c = integrating constant.

As u is equal to v in steady-state at $x = 0$, eq 3 is as follows:

$$u = v - k^2 \int x\, dx \tag{4}$$

So, the melting speed depends upon the initial velocity and the hysteresis of the past which means the effect of the temperature of the electrode.[1,2]

When we put $\dot{u} = d^2x/dt^2$ into eq 2,

$$\frac{d^2x}{dt^2} = -k^2 x \tag{5}$$

The general solution of eq 5 can be assumed as:

$$x = A \sin kt + B \cos kt \tag{6}$$

A, B = constant.

If $t = 0$, $x = B$, which means a displacement of the tip by some reasons at $t = 0$.

Differentiating eq 6,

$$\frac{dx}{dt} = Ak \cos kt - Bk \sin kt$$

Let us take $dx/dt = v$ at $t = 0$, $v = Ak$, and so, $A = v/k$

Thus, eq 6 is reduced as follows:

$$x = \frac{v}{k} \sin kt + B \cos kt \tag{7}$$

Rewriting,

$$x = \sqrt{B^2 + \frac{v^2}{k^2}} \sin (\varphi + kt) \tag{8}$$

$$\tan \varphi = \frac{Bk}{v}$$

Here, x means the variation of the arc length, and as far as the electrode fall is constant, it also means the change of the arc voltage which is proportional to the change of the arc length.

So, if we take E as the change of the arc voltage instead of x,

$$E = f\sqrt{B^2 + \frac{v^2}{k^2}} \sin (\varphi + kt) \tag{9}$$

here

$$\tan \varphi = \frac{Bk}{v}$$

f = constant concerning an arc column.

This is the equation expressing the ripple.

According to eq 9, the variation of the arc voltage forms a sine wave, and its period is proportional to k.

Assume that k is proportional to the arc current as is generally admitted, and the frequency of the ripple has the proportionality to the current.

On the other hand, the amplitude of the ripple is expressed as follows:

$$f\sqrt{B^2 + \frac{v^2}{k^2}}$$

and the initial condition is taken in steady-state under which $u = v$ and k increases with the increase of current as well as v, so that the amplitude hardly varies with the increase in the arc current.

3. METHODS OF EXPERIMENTS AND RESULTS

(1) *Method*

As illustrated in Fig. 2, the apparatus is very simple.

The automatic welder is necessary for feeding the electrode and maintaining the voltage constant.

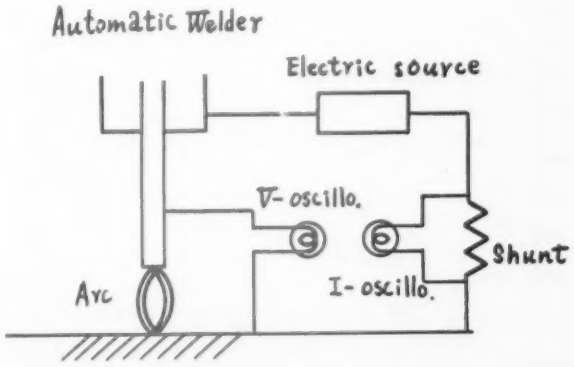


Figure 2

In other words, it is devised to ignite the arc continuously in steady-state.

The voltage is oscillographed between the plate and the point near the tip of the electrode in order to avoid the effect of the contact potential.

The oscillogram of the arc current is taken as the potential drop of the shunt in the arc circuit.

For convenience, all experiments are performed in the normal polarity with the d-c source.

The oscillographing duration is made as short as possible, i.e., the speed of the drum of the electromagnetic oscillograph is adjusted between $^{10}/_{100}$ and $^{20}/_{100}$ sec per one revolution.

This is due to the assumption that the irregularity of the controlling motors and of other parts may not influence the arc, in addition to that the response time of the automatic welder is previously measured.

To investigate the effect of the material of the electrode and the arc current, we have carried out some experiments about six kinds of electrodes for various arc currents.

The starting point of the oscillogram is always set at the point of time in steady-state at which the arc length is kept constant.

In fact, the constancy of the arc length in reference to every oscillogram has not any important meaning to our consideration.

(2) *Experimental Results*

All experimental results are oscillographed and analyzed.

Two or three parts of an oscillogram in which the arc current is constant are picked up, and the number of the peaks in the ripple of them is calculated, while its amplitude is measured.

The frequency and the amplitude of the ripple vs. the arc current are plotted in Figs. 3 to 8. Each represents a different electrode.

These series of results tell us as follows:

i. The ripple is a sine wave, though irregular.

ii. The frequency of the ripple is, as a whole, proportional to the current.

iii. The amplitude is not dependent upon the arc current, but rather constant.

iv. The frequency has different values according to the kinds of the electrodes or the coated materials, even in the same current.

v. As above, the amplitude depends on the coated materials, but its order is not significant.

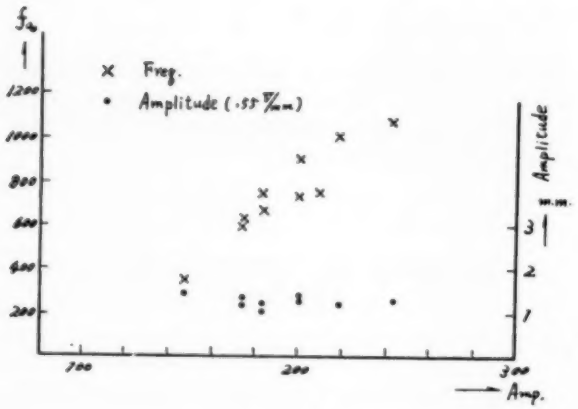


Figure 3

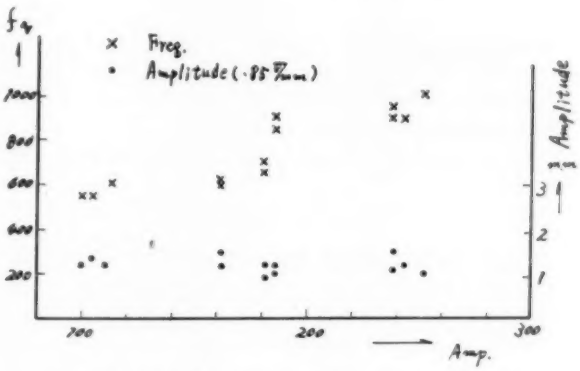


Fig. 5 RT-30, Jinto Electrode Co. (4 mm diam)

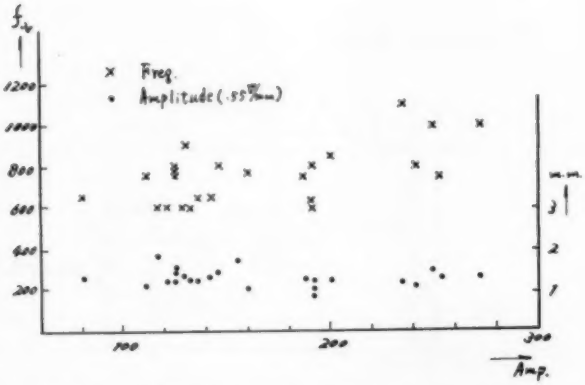


Fig. 4 Ishikawajima Heavy Ind. Co (4 mm diam)

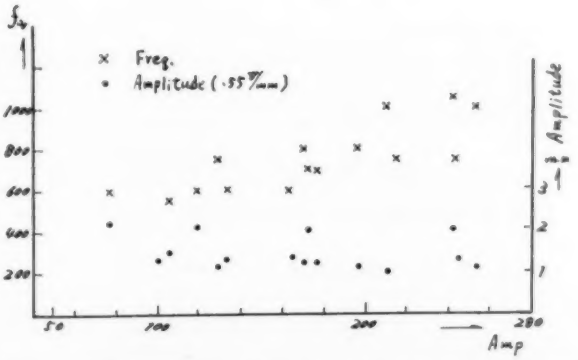


Fig. 6 Shihokuku Iron Manufacturing Co. (4 mm diam)

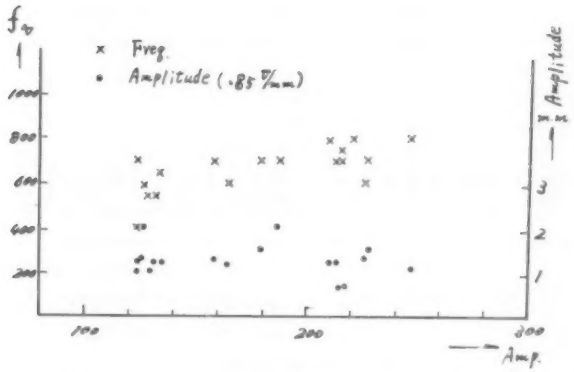


Fig. 7 ST-17, Jinto Electrode Co. (4 mm diam)

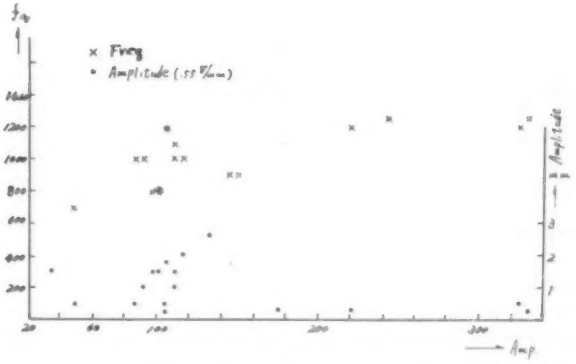


Fig. 8 Tungsten electrode (4 mm diam)

4. CONSIDERATION TO RESULTS

As above, we assumed the self-regulation of the arc in Section 2 and induced eq 1. Solving it under the proper initial condition, we have, as follows:

$$E = f\sqrt{B^2 + \frac{v^2}{k^2}}\sin(\varphi + kt)$$

$$\tan\varphi = \frac{Bk}{v}$$

f = constant.

In order to prove this, we should perform the experiment precisely and deliberately.

If the experimental results, to some extent, are coincident with eq 9, its reliability will be evidenced, and so the existence of the self-regulation in the arc will be admitted.

First of all let us examine the results:

i. The fact that the ripple forms a sine wave is in agreement with eq 9.

ii. The proportionality of the frequency to the current may be understood if k in sin depends upon the current.

iii. The amplitude hardly varies with the current. In eq 9, $\sqrt{B^2 + (v^2/k^2)}$ is constant, because v and k vary at the same order to make v/k constant if the initial condition is taken in steady-state. B is a constant independent of the current.

iv. The variation of the frequency with the electrode material will be understood through the fact that k depends on it.

v. The dependence of the amplitude upon the electrode material must be investigated about f.

As f is a constant concerning the potential gradient of the arc column, which is dependent on the material, it varies with the material.

As mentioned above, we have discussed the characteristics of the ripple and it seems that the reliability of eq 9, i.e., the assumption of eq 1, has been verified very precisely.

In other words, the existence of the self-regulation in the arc may be approved under the assumption of eq 1.

As for the relation between the sputtering and the self-regulation, we consider that the cause of the former is the self-regulation, and from this point of view, the external factor of the sputtering is recognized to correspond to the internal one of the self-regulation, as already discussed in Section 2.

5. EXPANSION TO ARC IN GENERAL

Let us discuss whether the above theory can be applied to the arc in general or not.

In eq 8 of Section 2, namely,

$$x = \sqrt{B^2 + \frac{v^2}{k^2}}\sin(\varphi + kt) \qquad (8)$$

here

$$\tan\varphi = \frac{Bk}{v}$$

B = constant.

Because x expresses the oscillation of the tip of the electrode we must substitute eq 8 in the equation of the arc in steady-state in order to investigate the conditions of the whole arc.

Taking Nottingham's equation[4] concerning the voltage, current and the arc length which is generally admitted at present, we have,

$$V = a + b(x_0 + x) + \frac{c + d(x_0 + x)}{I^n} \qquad (10)$$

here

V = arc voltage
I = arc current
a, b, c, d, n = constants
x = arc length in steady-state
x = variation of the arc length by the ripple

Rewriting it,

$$V = V_0 + bx + \frac{dx}{I^n} \qquad (11)$$

here

$$V_0 = a + bx_0 + \frac{c + dx_0}{I^n}$$

and so, V_0 is the arc voltage in steady-state and the

other terms show the varying parts of the arc voltage through the ripple.

Substituting this into eq 8, we have as follows:

$$V = a + bx_0 + \frac{c + dx_0}{I^n} + \left(b + \frac{d}{I^n}\right)\sqrt{B^2 + \frac{F^2}{k^2}}\sin(\varphi + kt) \quad (12)$$

Analyzing eq 12,

1st term: the term expressing the electrode fall
2nd term: the term concerning the length of the column and the material of the electrode
3rd term: the term concerning the current
4th term: the term by the self-regulation of the arc

Consequently, we are able to make sure of these terms through the proper experiments.

6. CONCLUSION

In this report, taking up the ripple of the arc voltage appearing generally in the welding arc, we have proposed the theory of self-regulation in the arc and carried it out in the experiments to verify it, in contrast to the previous explanation that the ripple is due to the oscillations of the automatic welder or the sputtering.

What we wish to say is the proof of the existence of the self-regulation in the arc has been presented in this paper.

Summarizing the results:

(*a*) Self-regulation of the arc seems to exist.

(*b*) Ripple of the arc voltage due to self-regulation forms a sine wave.

(*c*) Its frequency is directly proportional to current and depends on the material of the electrode.

(*d*) Its amplitude does not depend on current as far as in steady-state, but depends upon the material.

7. ACKNOWLEDGMENT

The authors are indebted to Mr. Sugihara for his suggestions to our experiment, and express their gratitude to Mr. Kimura and others for their assistance in obtaining the data.

Reference

1. Wolfgang and Finkelnburg, "The Physical Mechanism of the Low and High Current and Their Relation to the Welding Arc," *Trans. AIEE*, **70**, 800 (1951).
2. Wolfgang and Finkelnburg, "The High Current Carbon Arc and Its Mechanism," *Jnl. Appl. Phys.*, **20**, 468 (1949).
3. Engel and Steenbeck, "Elektrische Gasentladung," S. 119, S. 131.
4. Loeb, *Fundamental Pro. of Elec. Disch. in Gases*, p. 605.
5. Müller, A., Greene, W. J., and Rothschild, G. R., "Characteristics of Inert-Gas-Shielded Metal-Arcs," The Welding Journal, **30** (8), 717 (1951).

Fatigue Strength of Butt Welds Made with Different Electrodes

by G. Becker and R. Rieger

RECENT tests in connection with the September 1950 issue of the German standard 1913 showed that in fatigue the notch effect of internal defects in welds is outweighed by external notches. The metallurgical characteristics of electrodes also affect fatigue strength. Up to 1945 only 6020 electrodes were allowed for bridges, the core rod being mild steel or manganese alloy steel. The present tests were made with five types of electrodes $^1/_8$ and $^5/_{32}$ in. diam. Butt welds (70° V) were made in the flat position in open-hearth steel $^5/_{16}$ in. thick by an experienced operator. A bead was deposited on the reverse side of each joint. The root layer was deposited with $^1/_8$-in. electrodes, the top and reverse layers with $^5/_{32}$-in. electrodes. Some of the welds were planed and ground smooth. The welded plates were machined to specimens with a parallel section $^5/_8$ in. long, $^5/_{16}$ in. wide. The parallel section merged into a wider grip section with a radius of $1^3/_4$ in. Fatigue tests were made in a pulsator in accordance with German Standard 50100, both reversed tension-compression and pulsating tension being used. Stresses were computed on plate cross section. Fatigue tests were run to two million cycles.

The results are given in Table 1. Ti 18 and Es 33 had spray transfer and produced a smooth gradual junction of weld with plate. The globular electrodes Kb 52, Ti 13 and Ze 63 produced more abrupt junctions. The fatigue fracture started in unmachined welds almost always at the junction. In machined joints the fracture started sometimes in plate, sometimes in the junction and sometimes even in the weld.

The results show that the effect of internal defects on fatigue is less than that of external effects. Also the order of fatigue strength of the electrodes is changed by machining.

Table 1—Results of Fatigue Tests

	Fatigue limit, psi			
	Tension-compression		Pulsating tension	
Type of electrode	*Unmachined*	*Machined*	*Unmachined*	*Machined*
Unwelded plate*	...	±22,800	...	+42,700
Kb 52 lime 6015	±10,000	±22,800	+17,100	+42,700
Ti 18 heavy coated 6013	±14,200	±22,800	+27,000	+42,700
Es 33 heavy coated 6020	±11,400	±21,400	+20,600	+39,800
Ti 13 medium coated 6012	±7,100	±19,200	+12,800	+35,600
Ze 63 cellulosic 6010	±7,100	±18,500	+14,200	+31,300

* The plate contained 0.21–0.23 C, 0.51–0.53 Mn, 0.16–0.19 Si, 0.021–0.025 P, 0.032–0.040 S. Its yield and tensile strengths were 48,000–50,000 and 71,000–72,000 psi, respectively.

Abstract of "Vergleichende Untersuchungen dauerbeanspruchter Schweisverbindungen in Zusammenhang mit dem Elektrodentyp," published in *Schweisstechnik* (Berlin), **3**, 363–364 (December 1953) (Abstracted by Dr. G. E. Claussen.)

Penetration Factors in Metallic Arc Welding

by Roger C. Waugh and Otto P. Eberlein

METALLIC arc welding was first practiced in 1889, shortly after the invention of the arc lamp. Since then, there have been many major developments which have broadened the scope of metallic arc welding and indicated the broader potentialities of this method of joining metals: the manufacture of welding generators having more stable output, the development of the coated electrode for providing sound weld metal having more desirable mechanical properties, and the introduction of alternating current welding equipment. Unfortunately, research has lagged behind many empirical achievements because of ignorance of some of the basic mechanisms of the process.

More complete knowledge of arc characteristics and the factors governing arc force and the depth of weld penetration will allow a more complete understanding of the behavior of electrode coating components, and perhaps lead to the design of more efficient and economical electrodes.

Often welding operators desire electrodes that produce welds having a minimum of pentration into the parent metal, or electrodes with which they are able to obtain deep penetration in thick metal sections. It is with the hope of contributing to the theoretical understanding of this mechanism, and with an awareness of the fact that future improvements will to a large extent depend upon the progress of research that the work described in this paper was undertaken.

PURPOSE

The aim of this investigation was to determine the factors controlling the penetration of various arc-welding electrodes, and the reasons for the differences in penetration realized with different electrodes. Penetration, or depth of fusion, is the distance from the original surface of the parent metal to that point at which the fusion ceases. (See Fig. 1.)

Roger C. Waugh and **Otto P. Eberlein** are students in the Metallurgical Department of Cornell University.

Paper won first prize in the 1953 Davis Undergraduate Welding Award Contest.

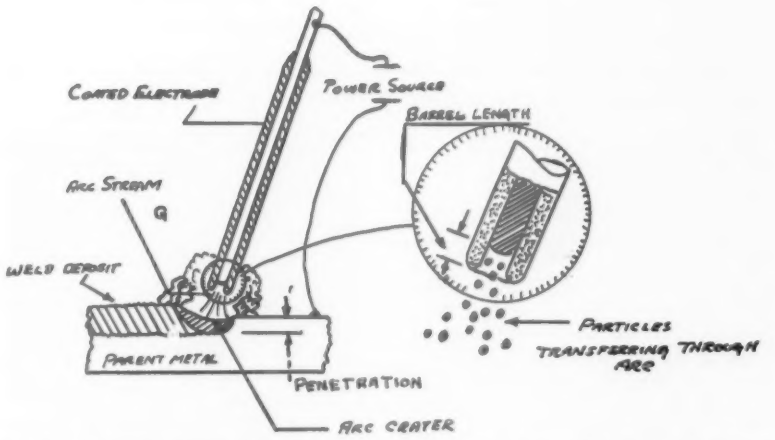


Fig. 1 Diagram of metallic arc welding, including illustration of barrel length and penetration

The following points were investigated as being potential influencing factors:

1. Size distribution of the particles transmitted through the arc.
2. Throwing power of the electrode. In this paper throwing power is defined as the force with which the particles are transmitted through the arc.
3. Effective barrel length of the electrode, where the effective value is defined as the distance from the tip of the electrode coating to the tip of the core rod. (See Fig. 1.)

EQUIPMENT

The details of the apparatus used to measure electrode throwing power are shown in Fig. 2. The two steel plates containing $^1/_4$-, $^3/_8$-, and $^1/_2$-in. diam colinear holes were spaced 3 in. apart, and were fastened to a standard which was electrically connected to the welding generator. Welding was done in the overhead position, welding on the bottom of the lower plate, passing over the drilled hole, and allowing the weld metal particles to be projected through the holes. The function of the upper plate was to block all particles passing through the hole in the lower plate which did not have a vertical trajectory. In this manner, an indication of directionality of the particle stream could be obtained from photographic exposures made while the electrode was traversing the hole in the lower plate. The scale behind the apparatus

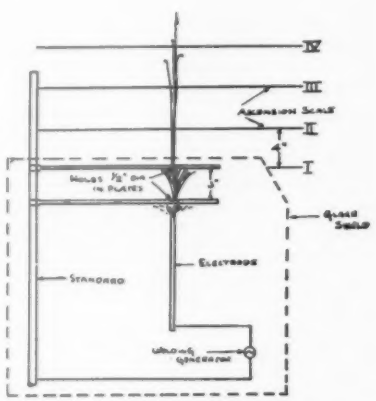


Fig. 2 Schematic diagram of apparatus used for measuring electrode throwing power

was used to measure the maximum height of rise of the particles. The scale lines were 4 in. apart. A glare shield was found necessary to minimize the stray light in the room and to keep direct light from the arc from the eyes of the observer and the camera used to record the trajectory and maximum height attained by the vertically rising particles.

Measurements of electrode penetration were made with a Brinell microscope, after the weld sections had been polished and etched. This microscope was also used to measure the characteristic barrel length of each electrode.

EXPERIMENTAL TECHNIQUE

The following 1/8-in. electrodes were chosen for investigation as possessing inherently different penetration characteristics and being in common commercial use:

AWS-ASTM classification No.	*Current and polarity utilized*
E6010	DC, Reverse
E6011	DC, Reverse
E6012	DC, Straight
E6013	DC, Straight
E6011	AC
E6013	AC

The first phase of this investigation was the study of particle size distribution of metal particles projected from the welding electrode, but not allowed to become part of a weld. Weld passes were made along the edge of a steel plate, so that many metal particles passed by the edge of the plate to be collected in a pan of water. These particles were dried, screened and weighed. Plots of cumulative weight percent retained versus mesh size were then made for each electrode.

The average height of the vertical trajectory of weld metal particles observed in the overhead welding test was utilized in the second phase of the investigation as a means of estimating the throwing power of each electrode. Preliminary passes indicated that the 1/2-in. diam hole was the most satisfactory to use. Overhead passes were made across the hole in the lower plate at approximately constant arc length and rate of pass for each electrode. The trajectory of the vertical particles passing through both holes was recorded by a camera using a time exposure. The average height of rise of the particles observed for each electrode could then be calculated utilizing the background scale on the film.

The last factor investigated was the barrel length of each electrode. In this step a pass in the vertical position was made across a steel plate at approximately constant arc length and rate of travel. The resultant barrel length was determined using a Brinell microscope. Four passes were made for each electrode, and the average value calculated and tabulated.

Since complete information concerning the depth of weld penetration to be expected from the electrodes under study was unavailable, an independent method of determining the relative penetration of each electrode was utilized. Beads were deposited by each electrode on a flat plate at a current of 100 amp, a constant arc length of 3/16 in. and electrode travel rate of 15 ipm. Each weld was sectioned and lightly etched with a solution of 50% nitric acid. The depth of the weld deposit was determined by a Brinell microscope.

Table 1

Electrode	*Current and polarity*	*Weight in grams of particles retained on screens, in mesh*						
		18	*30*	*50*	*70*	*100*	*200*	*200+*
E6010	DC, Reverse	2.3036	3.1697	1.7020	0.3624	0.0917	0.0337	0.0030
E6011	DC, Reverse	2.1316	2.0360	1.3612	0.7791	0.2013	0.0631	0.0420
E6012	DC, Straight	5.3161	4.6002	3.6324	0.6313	0.1303	0.0063	0.0020
E6013	DC, Straight	3.8371	3.5008	1.2529	0.8891	0.4600	0.0875	0.0042
E6011	AC	1.6137	1.7169	1.3204	0.5606	0.2136	0.0712	0.0039
E6013	AC	1.9105	1.1036	0.8670	0.2260	0.1131	0.0417	0.0131

EVALUATION OF EXPERIMENTAL RESULTS

The particle size distribution for each electrode is given in Table 1. From this screen analysis, a particle size distribution curve for the electrodes studied was drawn. (See Fig. 3.) The range is surprisingly narrow, so much so that it can be postulated that all electrodes may yield the same particle size distribution of the metal transferred through the arc

It is well known that the particles transferred through the arc are spherical in shape and that the slag is transferred as an external coating on the spheroids.[1]

It should be emphasized that this particle size distribution is not for particles of pure metal; the E6012 and E6013 electrodes produced a thicker coating of adherent slag on the particles than did the E6010 and E6011 electrodes. It is clear, therefore, that the actual metal transfer per weight of material transported through the arc will be less for the E6012 and E6013 electrodes.

This idea would then tend to introduce doubt as to the validity of the postulate that the particle size distribution for metal transfer through the arc is equivalent for all electrodes. The weight ratio of slag deposited to metal transferred, however, is sufficiently small, even for the E6012 and E6013 electrodes, that the variation in slag produced should not invalidate the original postulate.[2]

Comprehensive investigation of the relation of particle size to particle velocity for the E6010 electrode has been conducted.[3] Larson found that for large particles of steel, about 0.01 in. in diameter, moving through air at room temperature, the friction in the air becomes almost negligible compared to the retardation due to gravity. For particles 0.001 in. in diameter, however, the retardation due to friction becomes much larger than that due to gravity. To reach a given height a small particle must have a higher initial upward velocity than a large particle. In general, the smaller particles had the higher velocities, and thus both large and small particles were found at all heights.

It is to be noted from Fig. 3 that 80–90% by weight of the particles are 0.01 in. or larger in diameter.

This study suggests the value of further velocity distribution investigation and its subsequent correlation with particle size analysis data to attain optimum welding efficiency. For example, to achieve optimum electrode performance in an electrode exhibiting a narrow range of initial velocity distribution between large and small particles requires a particle size distribution favoring large particles.

The experimental data on the depth of penetration, shown in Table 2, are in relative agreement with the values of penetration reported in the literature. The fact that the maximum width of the zone of fusion decreases with increasing barrel length is entirely in accord with

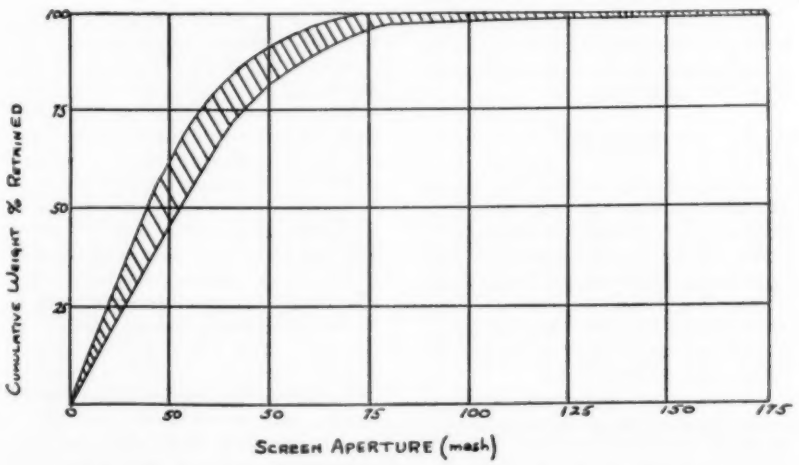


Fig. 3 Particle size distribution range for all electrodes tested

Table 2

Electrode	Current and polarity	—Experimental*— Depth, mm	Width, mm	Literature depth, mm†	Avg barrel depth, mm
E6010	DC, Reverse	1.30	6.76	2.0	−1.38
E6011	DC, Reverse	0.21	2.71	...	0.69
E6012	DC, Straight	0.36	4.64	1.2	−0.01
E6013	DC, Straight	0.11	1.26	...	1.05
E6011	AC	0.48	6.03	1.3	0.47
E6013	AC	0.27	2.96	0.5	1.49

* Experimental values: Bead made on flat plate at current of 100 amp, electrode travel rate of 15 ipm, and using $^1/_8$-in. electrode at a $^3/_{16}$-in. arc length.

† Literature values: From the *Welding Encyclopedia*, 12th edition; values are for the penetration of fillet welds made in the flat position on $^3/_8$-in. 1020 steel with $^1/_{32}$-in. electrodes.

earlier belief, for the barrel effects a directionality on the particle stream.

It was also found that the depth of penetration varied inversely with the barrel length. The E6010 electrode produced the greatest penetration. The barrel in this electrode was nonexistent. In fact, the tip of the core rod protruded past the tip of the coating. This condition is listed in Table 2 as a negative barrel length. The results obtained in the effect of barrel length on penetration may be surprising, for it would be logical to assume that the effect of the barrel in directing the particle stream would be greater in the longer-barreled electrodes, and that these electrodes would deliver more heat and a greater particle weight in a limited area (such as the space between the edges of two plates to be welded) than would a short- or negative-barreled electrode. Indeed, part of this assumption is borne out by Table 2, which shows decreasing width of bead with increasing barrel length. In an attempt to explain this paradox of decreasing depth of penetration with increasing barrel length, two postulates are advanced as possible controlling factors.[4]

1. The particles thrown into the weld region strike the weld piece with less force from a long-barreled electrode than from a short-barreled one.

2. A long barreled electrode develops less heat at the weld region than a short-barreled one, and thus operates with the weld region at a lower temperature. Since the metal in the weld region has a higher surface tension at the lower temperature, the arc blast produces a shallow crater. The result of this combination of effects is a shallow penetration with the long-barreled electrodes.

It cannot be assumed that all electrodes which exhibit the same average barrel length will produce the same depth of penetration. The composition of the coating must be considered, for the coating produces the barrel of which we speak. Minor base constituents will have a striking effect on the depth of penetration without markedly affecting the barrel length. The refractory tendencies and binder properties of each coating would provide an interesting study for correlation with penetration and effective barrel length.

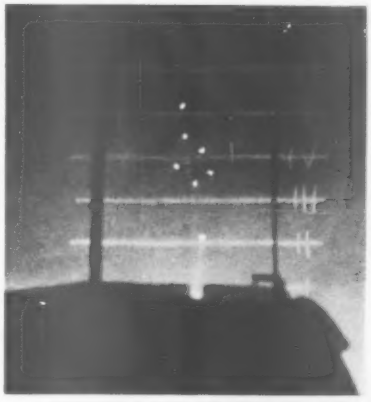


Fig. 4 Typical photograph showing results of throwing power test. The maximum height obtained by the observed particles has been emphasized for clarity in reproduction

Figure 4 is an example of the photographs taken to measure the throwing-power of each electrode. The maximum height attained by any particle is a function of its initial velocity and size, as previously noted. Since both of these are variables, the observed particle spread is to be expected.

Table 3

Electrode	Current and polarity	Average height of rise of particles observed, in.	Penetration, mm
E6010	DC, Reverse	5.5	1.30
E6011	DC, Reverse	14.5	0.21
E6012	DC, Straight	9.0	0.36
E6013	DC, Straight	17.0	0.11
E6011	AC	13.0	0.48
E6013	AC	16.0	0.27

Table 3 shows the relation between electrode throwing power and penetration. The data taken show that throwing power varies inversely with penetration. From these observations, it should be concluded that the first postulate advanced above is untrue, and that particles from electrodes of long barrel length are thrown against the immediate weld region with more force than those from short-barreled electrodes.

This leaves only the postulate of lower penetration with lower temperature to be considered. This fact has been established through experiment and experience—E6012 and E6013 have long been known, and were designed, as "cold" electrodes, producing a high, narrow bead with low penetration.[5] The factor responsible for the shallow penetration of these electrodes is obviously the lower heat generated at the weld region by these electrodes. This fact has been suspected and partially proved by earlier experimentation.[6] It is now seen to be the controlling factor in penetration differences for all electrodes—producing shallow or deep penetration despite the increase or decrease in throwing power of the electrode. The true import of heat considerations in the explanation of penetration was not realized previously since the effect of varying barrel length was not considered. In turn an explanation of the variation in heat produced from electrode to electrode must be based on the coating of the electrode and the inherent barrel length.

E6012 and E6013 electrodes were tested with alternating, as well as direct current. The behavior regarding the correlation of barrel length, throwing power and penetration is similar to that of the DC group. One should not attempt direct comparison between the groups because the basic mechanisms of metal transfer through the arc are somewhat different for alternating as compared to direct current.[7]

Note should be made of the different electrode coatings used in this experiment because their composition differences produced variations in both throwing power and barrel length.

The high potassium coatings evidently were the more refractory, maintaining the longer barrel and retaining greater amounts of arc heat than did the high sodium coatings. The high titania coatings slagged more rapidly than the high cellulose ones, which depend on the production of a controlled atmosphere to protect the molten metal.[8]

The discussion of heat, force and penetration has been reduced to its simplest terms in an effort to gain a working knowledge of the basic principles and problems of the electric arc process. Before a rigorous investigation could be made on the physical laws governing the phenomena reported herein, further work would have to be done on such fundamental problems as determination of arc and crater temperature, arc blast force and coating behavior. Full utilization of the arc-welding process can only be achieved by attaining a clear insight of its basic principles.

Bibliography

1. Wisniewski, P. J., and Thomas, D. A.,

'Metal Transfer in Arc Welding," *Cornell Engineer* (April 1952).
2. Henry O. H. and Claussen, G. E. *Welding Metallurgy*, Vol. I, p. 255 (1940).
3. Larson, L. J., "An Exploration of a Modern Welding Arc," THE WELDING JOURNAL, **15** (10), 14 (1936).
4. Doan, G. E., and Lorentz, R. E., "Crater Formation and Force of the Electric Welding Arc in Various Atmospheres," *Ibid.*, **20** (2), Research Suppl., 103-s (1941).
5. Herres, S. A., "Arc Welding of Alloy Steels," *Trans. ASM*, **33**, 535 (1944).
6. Muller, J. A., "How to Select Arc Welding Electrodes," *Am. Machinist*, **80**, 854 (1936).
7. Alexander, A. F., "The Calorimetry of the Arc," *Trans. AIEE*, **49**, (4), 519 (1930).
8. Doan, G. E., and Weed, H. F. "Metal Deposition in Arc Welding," THE WELDING JOURNAL, **11** (9), 31 (1932).

Oxy-Acetylene Stress Relieving of Pressure Vessels

Low-temperature stress relief is an inexpensive means for securing reduction in shrinkage stress of pressure vessels made of low-carbon steels

by Hans Kunz

THERE have been numerous foreign papers[1–8] on the relief of welding shrinkage stresses in arc-welded joints by heat treatment at about 200° C. Four German papers[9–12] provide a research basis for the empirical results. With few exceptions,[13] previous tests have been confined to plane plates of finite length. The present paper is intended to show the value of low-temperature stress relief for a pressure vessel.

Abstract of "Erfahrungen beim autogenen Entspannen von Behaltern," published in *Schweissen und Schneiden*, **6**, 216–225 (1953). (Abstracted by Dr. G. E. Claussen.)

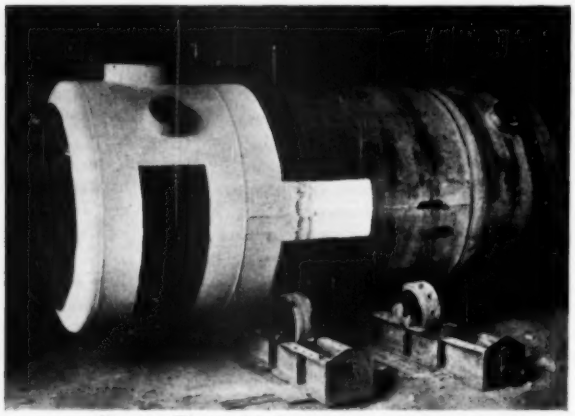


Fig. 1 The welded experimental vessel

The vessel, Figs. 1 and 2, was built symmetrically in two halves, one-half being low-temperature stress relieved. The boiler plate (Grade MI) contained 0.08 C, 0.01 Si, 0.48 Mn, 0.038 P, and 0.025 S. The mechanical properties were: yield point = 31,500 psi, tensile strength = 54,000 psi, elongation = 29.3% in 10 diam, Brinell hardness = 105, DVM notch-impact value = 15.1 mkg/cm². The plate was 0.47 in. thick. Welding was done manually in the flat position with a 6020 electrode on reverse polarity. Four layers were deposited in the V-butt welds. The first layer was deposited with $^{1}/_{8}$-in. electrodes at 180 amp. The other layers were deposited with $^{5}/_{32}$-in. electrodes at 220 amp. Then the root was chipped out and a reverse bead was deposited with $^{5}/_{32}$-in. electrodes at 220 amp. The fillet welds for the nozzles were made in two passes, one on each side, Fig. 3.

The stress-relieving procedure was the same as for plane plates, because temperature measurements were the same for the plane plates as for the shell. The temperature difference required between weld and heated zone was calculated from the yield point:

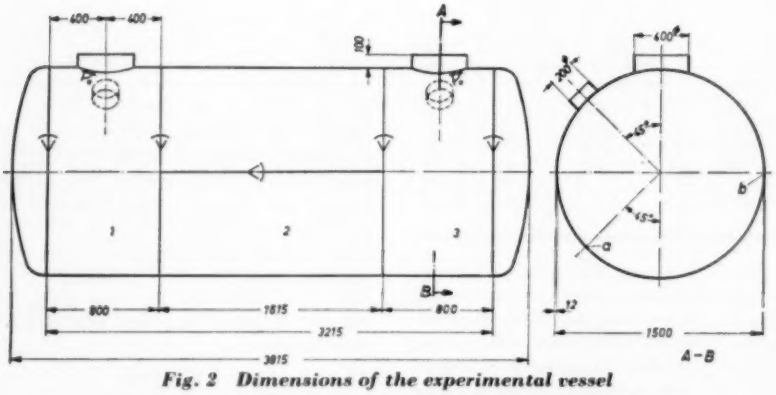


Fig. 2 Dimensions of the experimental vessel

(a) location of longitudinal welds in Shells 1 and 3. (b) location of longitudinal weld in Shell 2. Total length of welds = 85 ft. Dimensions in mm.

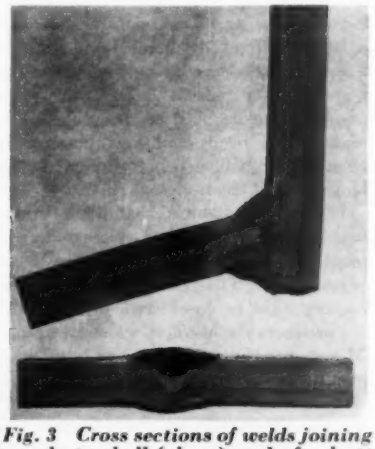


Fig. 3 Cross sections of welds joining nozzle to shell (above) and of a butt weld in the shell (below)

$$\Delta t = \frac{\text{Y. P.}}{\beta \times E} = \frac{31{,}500}{12 \times 10^{-6} \times 28.5 \times 10^{6}} = 92^\circ \text{ C}$$

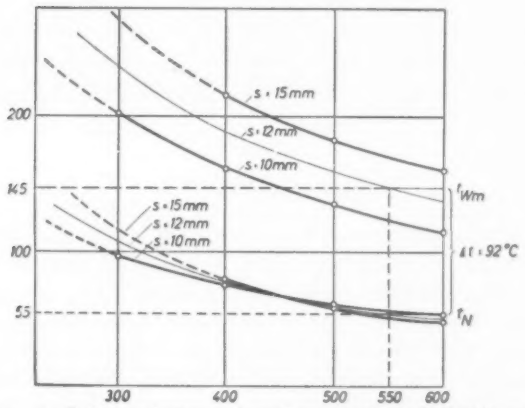
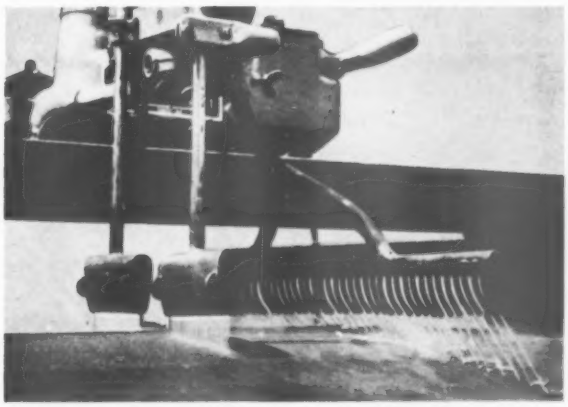


Fig. 4 Relation between travel speed of torch (horizontal axis) and temperature (vertical axis) for three plate thicknesses, 10, 12 and 15 mm

t_N = temperature in weld, ° C.; t_{Wm} = average temperature in heated zone, ° C.; width of torch = 4 in. Distance between centerlines of torches = 7.1 in.



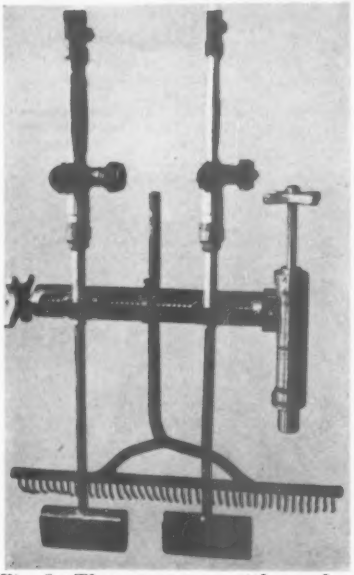


Fig. 5 The apparatus with torches 90° to the weld

where β = coefficient of thermal expansion per ° C and E = modulus of elasticity. Figure 4 shows that for a temperature difference of 92° C (166° F) the travel speed of the torches should be 550 mm/min (21½ ipm). Figure 4 applies when the long axis of the torches is perpendicular to the weld, as in Fig. 5. Earlier work[12] showed an advantage in having the axes of the torch at 45° to the weld, Fig. 6. This arrangement was used for the present work. Because the heat effect is more intense the travel speed was raised 10%. The settings

Fig. 6 Treating a longitudinal weld with torches 45° to the weld

Fig. 7 View of the water-quench side on a girth seam

Fig. 8 View of the torches on a girth seam

for stress relieving the longitudinal and girth welds were:

Width of torch: 100 mm (4 in.).
Distance between centerlines of the two torches: 180 mm (7.1 in.)
Distance of torch from surface: 25 mm (1 in.)
Travel speed: 600 mm/min (24 ipm)

A series of tests on plane plates showed that the best settings for relieving the fillet welds were:

Width of torch: 60 mm ($2^1/_2$ in.)
Distance between centerlines of the two torches: 125 mm (5 in.)
Distance of torch from surface: 25 mm (1 in.)
Travel speed: 400 mm/min (16 ipm).
Angle of torch to weld: 90°

Figure 6 shows the relieving of a longitudinal weld, the torches being moved by a travel carriage. Figures 7 and 8 show the relieving of a girth weld, the vessel being rotated. The torch was designed for flame priming. For a torch 4. in wide there were 27 holes each 0.020 in. diam. For a torch $2^1/_2$ in. wide there were 14 holes. The acetylene consumption was 170 lph per cm of torch width (2.3 cfh per inch of width). About 10% more oxygen was used than acetylene. At a distance of 130 mm (5 in.) behind the torches was the water quench consisting of 44 holes 0.079 in. diam. The water flow was 0.35 to 0.53 cfm. More water was required than on plane plates, because the water ran off. Figure 9 shows the relieving of the girth seam between shell and head. The outer torch is tilted 30° to the axis to allow for the curvature of the head. Figure 10 shows the set up for the fillet welds. One torch heated the shell, the other heated the nozzle. The torches were perpendicular to the axis of the weld and were guided manually.

Fig. 9 Treating the head-to-shell weld. The head is shown by the chalk mark

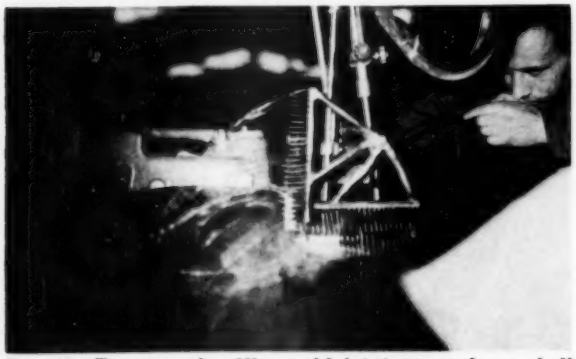


Fig. 10 Treating the fillet weld joining nozzle to shell

MEASUREMENTS

Three methods were considered: (1) Mathar-Soete,[14, 15] (2) Jonassen,[16] and (3) Campus,[17] but these are unsatisfactory, according to Gunnert.[18]

1. The changes in the dimensions of a drilled hole are measured. The notch effect of the hole concentrates the stress and leads to higher measured stresses than are actually present.

2. Electric resistance strain gages are fastened to the plate, which then is drilled out. Stresses are measured as averages over a distance of about $1^1/_2$ in., which reduces the sensitivity.

3. Mechanical extensometers are sited in spherical impressions arranged as rosettes. The rosettes are cut

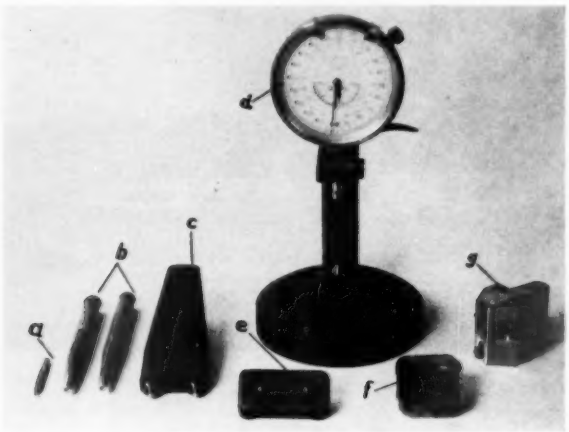


Fig. 11 The extensometer

(a) Preliminary drill, (b) pinches, (c) gage length punch, (d) dial gage, (e) gage for length, (f) balls $^1/_{16}$ in., diam, (g) extensometer.

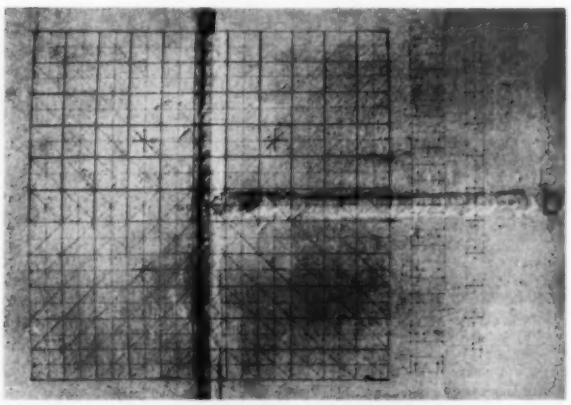


Fig. 12 Rosettes at intersection of girth seam (a) with longitudinal weld (b)

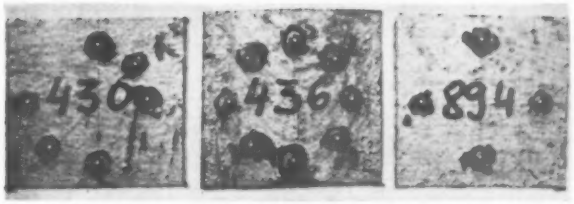


Fig. 13 Squares with different arrangements of gage lengths

out. This method also suffers the disadvantage of a long gage length and a possibility of $\pm 2\mu$ error.

In Gunnert's method the stresses are measured on a gage length of 9 mm (0.35 in.) with a mechanical extensometer with an error of $\pm 0.3\mu$ equivalent to 1850 psi. The gage rosettes are trepanned. This is an excellent method but was not available to the author, who used the Campus method (No. 3).

Our extensometer is shown in Fig. 11, the gage length being 0.79 in. The steel balls were $^1/_{16}$ in. diam. The accuracy was $\pm 2\mu$ equivalent to ± 2800 psi. Temperature corrections were applied because a change in temperature of 4° C was equivalent to 1μ. The network of rosettes is shown in Fig. 12. Three rosettes cut from the plate are shown in Fig. 13. Since the axes of principal stresses at the locations of peak stresses deviated from the axis of the weld in which they occurred by no more than 5°, there was no error from the practical standpoint in assuming that the longitudinal and transverse stresses were identical with the principal stresses. Poisson's ratio was applied to the squares ($1^3/_{16} \times 1^3/_{16}$ in.) cut from the vessel. The correction averaged 4.2% and accounted for the transverse contraction brought about by the biaxial stress. Well over a thousand gage lengths were measured, about ten measurements being made on each before and after cutting out. At weld intersections the

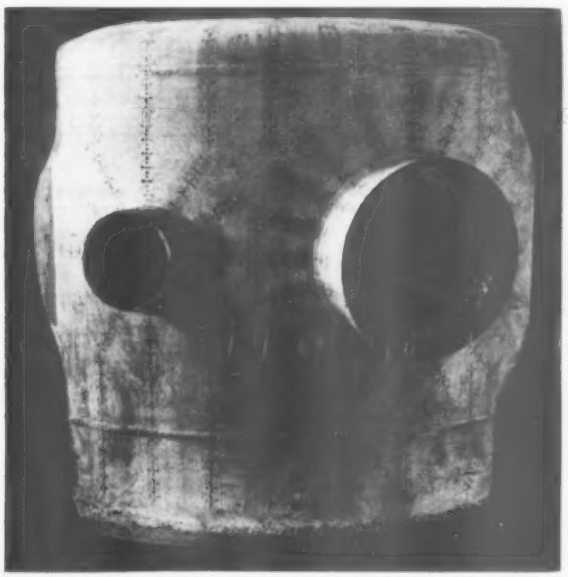


Fig. 14 Part of the vessel cut out, showing the gage lengths

Fig. 15 Stages in the cutting out of gage lengths

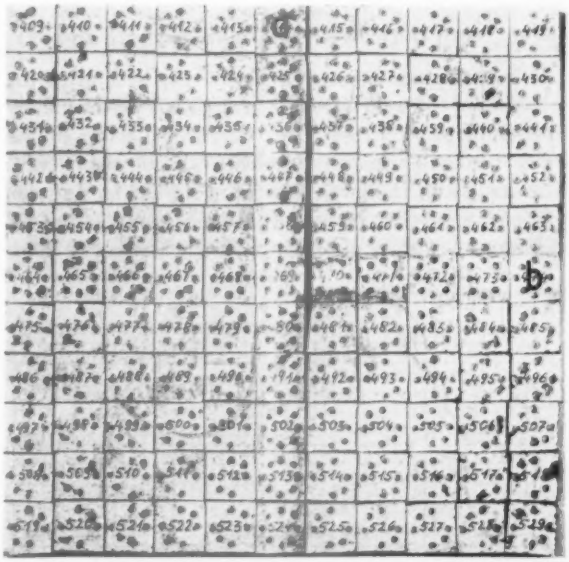


Fig. 16 Cut out rosettes at intersection of girth seam (a) with longitudinal weld (b)

Fig. 17 Cutting out gage squares with the band saw

pattern of rosettes is shown in Fig. 11. The rosettes around the nozzles are shown in Fig. 14. Each line of measurement perpendicular to a weld contained 11 rosettes; one on the weld and five on each side. The lines of measurement were 18° apart on the large nozzle, $22^1/_2$° apart on the smaller nozzle.

The vessel was cut up in three stages: (1) large zones were cut out by water cooled torch cuts. To reduce the heat effect hydrogen was used. The torch cuts were at least $4^3/_4$ in. from the nearest gage length. (2) further subdivision by hacksaw. (3) cutting into $1^3/_{16}$ in. squares by band saw. The cutting process is illustrated in Figs. 15 to 17.

RESULTS

Since there is insufficient space to present all the measurements, only the more important results will be summarized.

Girth Seam Between Two Shells (Figs. 18 and 19)

The shrinkage stresses of 27,000 psi tension in the direction of the weld were reduced to 8500 psi tension by low-temperature stress relief, which also removed the stress peaks. Transverse stresses were lowered 60%. The results on the girth seams are similar to those on plane plates. Similar results were obtained on a vessel 10 ft diam., 17 ft long, 0.67 in. wall thickness, Fig. 20.

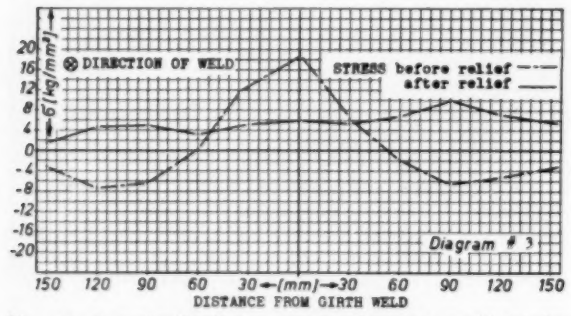

⊗ DIRECTION OF WELD
STRESS before relief
after relief
σ (kg/mm²)
Diagram # 3
150 120 90 60 30 ←(mm)→ 30 60 90 120 150
DISTANCE FROM GIRTH WELD

Fig. 18 Longitudinal stresses in the girth weld joining Shells 1 and 2 before and after low-temperature stress relief

Direction of welding into the plane of the diagram. Horizontal axis: Distance from girth weld, mm. Vertical axis: Stress, kg/mm.²

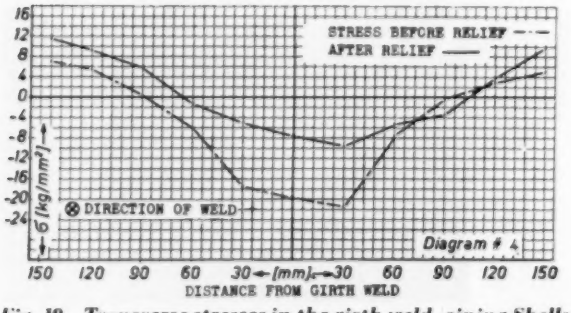

STRESS BEFORE RELIEF
AFTER RELIEF
⊗ DIRECTION OF WELD
σ (kg/mm²)
Diagram # 4
150 120 90 60 30 ←(mm)→ 30 60 90 120 150
DISTANCE FROM GIRTH WELD

Fig. 19 Transverse stresses in the girth weld joining Shells 1 and 2 before and after stress relief

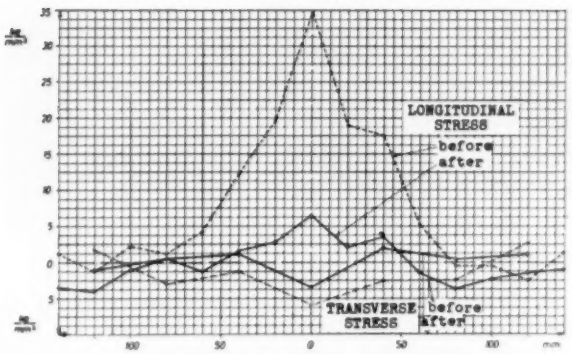


Fig. 20 Longitudinal and transverse stresses in a girth weld in a special vessel, 0.67-in. wall

Intersection of Girth with Longitudinal Welds (Figs. 21 and 22)

At the intersection the longitudinal stresses of the girth weld become transverse stresses of the longitudinal weld. The left side of Figs. 21 and 22 shows the stresses in the girth weld. The right side shows the girth stresses modified by the longitudinal weld. Stress relief lowered the maximum longitudinal stress of 14,200 psi tension to 8500 psi tension. The maximum value of longitudinal stress in the girth weld at the intersection was not very high and was only half the stress found in the weld at a distance from the intersection. Stress relief did not reduce the longitudinal stress in the girth weld to any extent and created

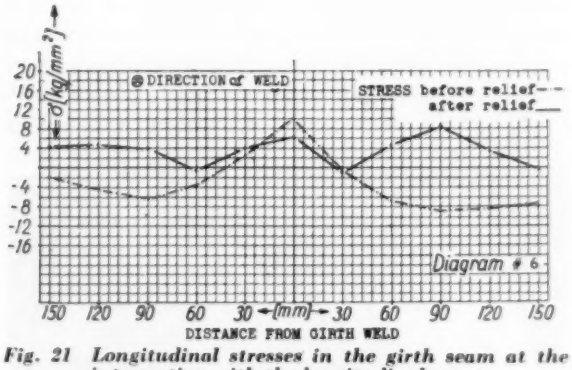

⊗ DIRECTION of WELD
STRESS before relief
after relief
σ (kg/mm²)
Diagram # 6
150 120 90 60 30 ←(mm)→ 30 60 90 120 150
DISTANCE FROM GIRTH WELD

Fig. 21 Longitudinal stresses in the girth seam at the intersection with the longitudinal seam

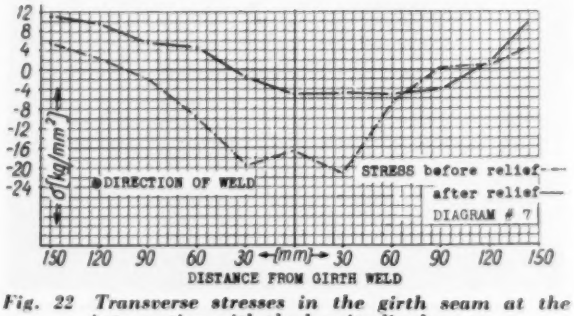

⊗ DIRECTION OF WELD
STRESS before relief
after relief
DIAGRAM # 7
σ (kg/mm²)
150 120 90 60 30 ←(mm)→ 30 60 90 120 150
DISTANCE FROM GIRTH WELD

Fig. 22 Transverse stresses in the girth seam at the intersection with the longitudinal seam

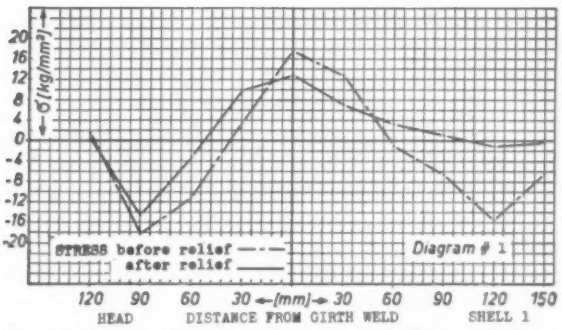


Fig. 23 Longitudinal stresses in the girth seam joining head with shell 1

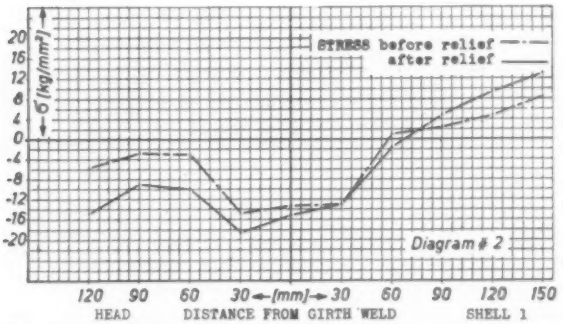


Fig. 24 Transverse stresses in the girth seam joining the head with shell 1

another stress peak, which however, was below the maximum longitudinal stress after welding. Better results would have been obtained if the travel speed had been reduced 20% for the intersections.

The Girth Weld Joining Head to Shell (Figs. 23 and 24)

The knuckle of the head exerts considerable restraint and accounts for the unsymmetrical distribution of stress in this girth seam. The closer the knuckle to the seam, the more pronounced is its effect. Stress relief is more effective on the shell side than on the head side. The knuckle distance was particularly short in this vessel and was less than is specified in German DIN specifications. Heating the rounded portion of the head did not relieve the longitudinal compressive stress much. The transverse stresses were not lowered at all because the head was too short. A comparative test was made on another vessel with 0.79 in. wall thickness in the head, whose height was 8 in. to the knuckle. The shell was 0.67 in. thick. Low-temperature stress relief reduced the longitudinal tensile stress in the girth seam, Fig. 25, from 36,500 psi to 10,800 psi. The transverse stresses in the longitudinal weld also were lowered considerably. This comparison shows that low-temperature stress relief is effective if standard head dimensions are used.

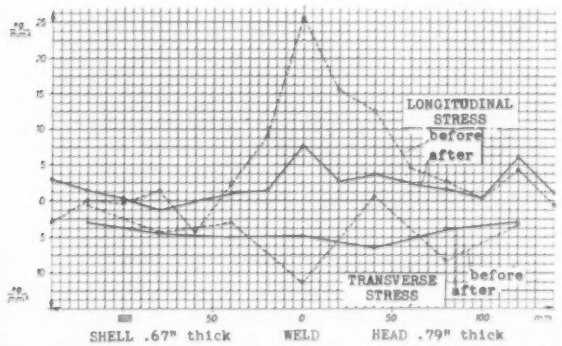


Fig. 25 Longitudinal and transverse stresses in a girth weld in a special vessel. Longitudinal stresses above; transverse stresses below

Fillet Welds (Figs. 26 and 27)

The travel speed was 16 ipm in Fig. 26 and 12 ipm in Fig. 27. Figure 26 shows a 38% reduction in longitudinal stress from 48,500 psi to 30,000 psi. The slower speed in Fig. 27 reduced the longitudinal stress 56% from 40,000 to 17,700 psi. In both instances the transverse stresses were small, and were not changed much by stress relief. The stresses could not be determined with sufficient accuracy in the weld of the smaller nozzle. However, the compressive longitudinal stress in the shell close to the weld was 23,000 to 26,000 psi. The compressive longitudinal stress in the wall of the nozzle was much lower: 8500 to 11,500 psi. After stress relief these stresses were reduced to ±4000 to 6000 psi. There was an 80 to 90% reduction of the shrinkage stresses.

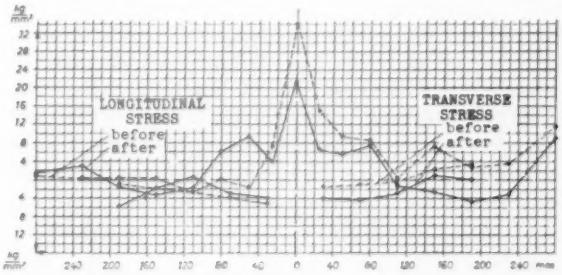


Fig. 26 Longitudinal and transverse stresses in fillet welds before and after relief. The longitudinal stresses rise to a peak at the weld. Travel speed = 16 ipm

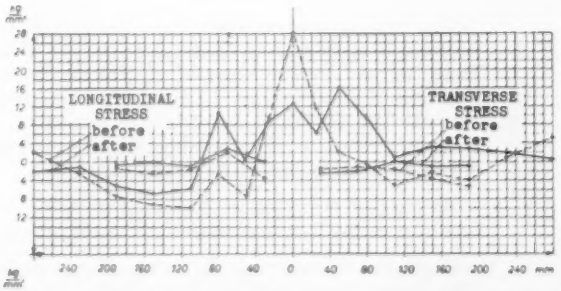


Fig. 27 Longitudinal and transverse stresses in fillet welds before and after relief. The longitudinal stresses rise to a peak at the weld. Travel speed = 12 ipm

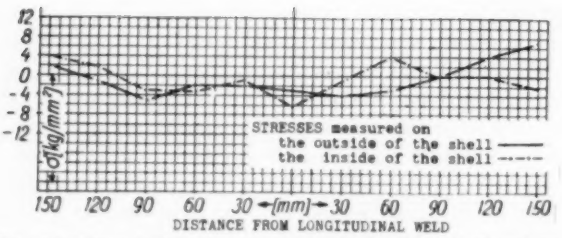


Fig. 28 Longitudinal stresses in the girth weld after low-temperature stress relief

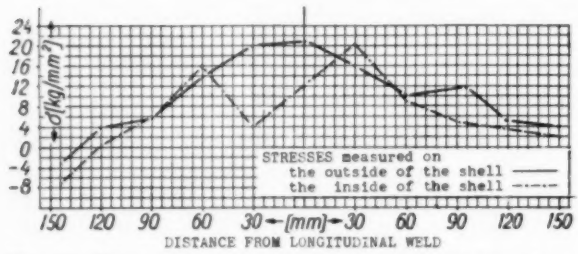


Fig. 29 Transverse stresses in the girth weld after low-temperature stress relief

The Inner Wall (Figs. 28 and 29)

The heating for low temperature stress relief is done on one side only. Measurements showed that the reverse side of the plate reached nearly the same temperature as the upper side. Stress measurements were made at several locations both on the upper side and the reverse side of the wall of the shell. The results in Figs. 28 and 29 show that measurements on both sides yield the same results.

SUMMARY

A study was made of stress relief in welded vessels using temperatures below 200° C. The results show that a worthwhile reduction in stresses can be secured by simple apparatus. The results confirm earlier tests on plane plates. The reduction in longitudinal stresses in the shell girth seam was 69 to 80%; for transverse stresses the reduction averaged 60%. These results are practically the same as for plane plates. The intersection of the girth seam with a longitudinal weld did not contain high stresses after welding.

The distribution of stresses in the head seam was unsymmetrical because the seam was too close to the knuckle. With standard heads the longitudinal stresses are reduced 70%. The travel speed for fillet welds should be reduced 40 to 50% compared with butt welds if a 50% reduction of stress is to be attained. Transverse stresses in fillet welds between plane plates are not changed much by low-temperature stress relief.

We conclude that low-temperature stress relief is an inexpensive means for securing worth-while reduction in shrinkage stress in ductile materials. For certain applications it is equivalent to the well-known furnace heat treatments, although no change in structure is involved. The process should be applicable to the construction of pressure vessels and ships.

References

1. Greene, T. W., "Evaluation of Effect of Residual Stresses," The Welding Journal, **28** (5), Research Suppl., 193-s to 203-s (1949).
2. Greene, T. W., and Holzbaur, A. A., "Controlled Low Temperature Stress Relieving," *Ibid.*, **25** (3), Research Suppl., 171-s to 185-s (1946).
3. Kraus, R., "Radiographing and Controlled Low-Temperature Stress Relieving of Welded Tanks for Wet Seal Gas Holder," *Ibid.*, **26**, 1073-1079 (1947).
4. Greene, T. W., "Welding Stresses Dissipated by Low-Temperature," *Steel*, **123**, S. 78–82 (1948).
5. Ryan, W., "Methods of Stress-Relieving," The Welding Journal, **23** (6), 536, (1944).
6. Soete, S., "Possible Methods of Measuring the Relief of Internal Stresses, *Extrait de la Soudure*," No. 3 (1948).
7. Soete, W., Vanerombrugge, R., "An Industrial Method for the Determination of Residual Stresses."
8. Brodsky, A. Y., "New Facts on the Straightening of Welded Aircraft Structures," *Eng. Digest*, **10** (5), (1949).
9. Wellinger, K., and Ludwig, N., "Reducing Shrinkage Stresses Due to Welding by Progressive Heating below 200° C," *Schweissen und Schneiden*, **3**, 344 (1951).
10. Kunz, H., "Flame Stress Relief of Welds," *Mitt. der BEFA*, No. 16 (1951).
11. Wolff, L., and Mantel, W., "Stress Relief with a Quenching Torch," *Schweissen und Schneiden*, **3** (1951). (Special issue.)
12. Kunz, H., "New Developments in Low Temperature Stress Relief," *Mitt. der BEFA*, No. 15 (1952).
13. Ginger, K., and Nass, R., "Low Temperature Stress Relief of Circular Sections, *Energie*, **4**, No. 6, 129–134 (1952).
14. Mathar, J. J., *Arch. Eisenhüttenwes.*, **6**, 277–281 (1933).
15. Soete, W., and van Crombrugge, R., "Measuring Shrinkage Stresses through the Thickness," *Lastijdschrift*, No. 1 (1948).
16. Meriam, J. L., DeGarmo, Paul, and Jonassen, F., "A Method for the Measurement of Residual Stresses," The Welding Journal, **25** (6), 340-s to 343-s (1946).
17. Campus, F., "Research on Welded Structures," Liège, *Sciences et Lettres* (1946).
18. Gunnert, R., *Arcos*, **28**, No. 121.

WRC Bulletin No. 17

The Welding Research Council has just issued Bulletin No. 17 of its Bulletin Series. This Bulletin is entitled, "A Critical Survey of Brittle Failure in Carbon Plate Steel Structures Other Than Ships," by Professor M. E. Shank, Department of Mechanical Engineering, Massachusetts Institute of Technology. This report was prepared for the Committee on Ship Structural Design, of the National Academy of Sciences—National Research Council. The Committee on Ship Structural Design is advisory to the Ship Structures Committee which supported the project as part of its research program.

No similar correlation on nonship failure data exists, and this survey was therefore undertaken in order to supplement the study of ship failures.

Copies of this 48 page Bulletin may be ordered from the American Welding Society, 33 West 39th Street, New York 18, New York. Price $2.00.

The Fatigue Factor in Welded Design

Methods of utilizing the fatigue factor in design are discussed and illustrated including examples for butt and fillet welds

by A. Erker

FIVE factors are involved in design: (1) The maximum stress the part can carry, S_e. (2) The permissible stress, S_z. (3) The stress actually observed in service, S. (4) The desired safety factor $S_e/S_z = F_{min}$. (5) The actual safety factor $S_e/S = F$.

The static yield and tensile strengths determined on straight specimens usually are the basis for computing S_e. Many years ago Bach referred to the importance of fatigue in design. His recommendations with recent ones are summarized in Table 1. The data for unwelded plate, butt weld and fillet weld are taken from the 1951 issue of Section 4 of the German Railways Specification for Welded Plate Girder Railway Bridges. Fatigue results, although usually reported[1] for uniform cycles of reversed stress, also have been determined for pulsating and other types of stress. Notches, while having little effect on the tensile strength of ductile materials,[2, 3] are of great importance in fatigue.

Table 1—Ratio of Permissible Stresses for Mild Steel

Part being designed	*Ratio of Permissibile Stresses** Case I	Case II	Case III
General data from Bach	1	0.67	0.33
General data from German Engineering Handbook *Hütte*, Vol. I, 26th ed.	1	0.6	0.5
Unwelded plate	1	1	0.93
Butt weld	1	1	0.64
Fillet weld	1	0.5	0.29

* Case I = static stress; Case II = fatigue stress, zero to maximum tension; Case III = fatigue stress, ± maximum.

There are two ways of computing fatigue strength in the presence of notches. In one method the peak stress appearing at the base of the notch is compared with the fatigue strength determined on an unnotched specimen. It must be remembered, however, that notched specimens often withstand higher peak stresses in fatigue than unnotched specimens of the same material. The attempt to solve this difficulty by the introduction of the "notch sensitivity" factor[4] is not successful.

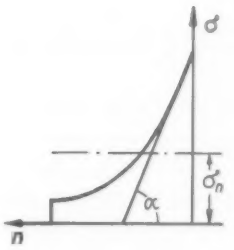


Fig. 1 Definition of the steepness of the stress peak at a notch

Tan $\alpha = d\sigma/d_n$ = steepness of stress peak; σ_n = nominal stress.

The notch sensitivity factor depends not only on the material but on the type of notch and the level of stress.[1] In a refinement of this method not only is the peak stress considered but also the stress gradient, Fig. 1, from the location of maximum stress.[5-7] With the aid of another material constant, the fatigue strength can be computed. This method has been applied to welds,[7] but more experience must be acquired before the method can be put to practical use.

The second method, which is in practical use, utilizes the simplified stress system illustrated in Fig. 2. The method does not consider the actual stress S_{max} in Fig. 2, but a fictitious average stress, S_{dk} in Fig. 2, called the nominal stress, also called the shape strength.[8]

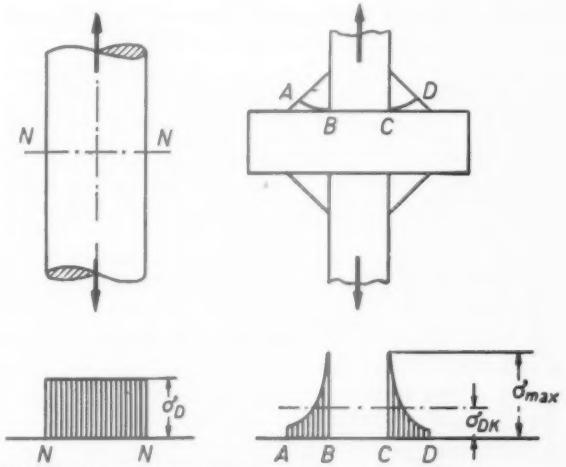


Fig. 2 Comparison of the fatigue strength of an unnotched bar with that of a fillet-welded joint

σ_D = fatigue strength of smooth bar; σ_{DK} = fatigue strength of fillet welded joint, expressed as nominal stress, that is, assuming uniform stress distribution; σ_{max} = peak stress at base of notch, calculated on the fatigue strength and assuming purely elastic behavior of the joint.

Abstract of "Berechnumg von Schweissverbindungen bei veranderlicher Beanspruchung," published in *Schweissen und Schneiden*, **5**, 400–417 (1953). (Abstracted by Dr. G. E. Claussen.)

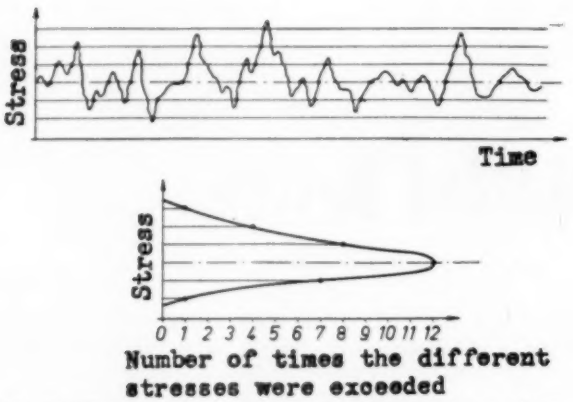


Fig. 3 The development of a stress frequency curve from stress measurements in service

The number of times the curve in the upper diagram exceeds each stress level in the rising direction is plotted on the frequency diagram

The ratio of the shape strength to the fatigue strength of an unnotched specimen is expressed by a series of factors, evaluated for welded joints by Bobek.[9, 10] These factors allow us to compute the permissible amplitudes of stress for welded joints from the permissible amplitudes for unwelded material. This method, as well as the method developed for welded bridges, will be discussed further.

NON-UNIFORM AMPLITUDE OF STRESS

There have been a number of studies in which cycles of low stress have been followed by cycles of high stress and inversely.[11–15] Particularly valuable have been studies in which, as in service, the stress cycle has been varied periodically during the fatigue test.[16–19] These studies have been based on measurements[19–27] of the frequency of stresses of various magnitudes in service. With special extensometers frequency curves[26, 27] of the type shown in Fig. 3 have been constructed. These curves require only a short time to construct. From them have been devised fatigue tests with varying amplitudes of stress, Fig. 4, to estimate service life under service stresses. A material may fail after a given program of blocks of stress cycles. In a second program all stresses are multiplied by a constant factor. Failure will occur after fewer cycles than in the first program. After several programs a curve similar to the usual endurance curve is obtained relating stress level to life

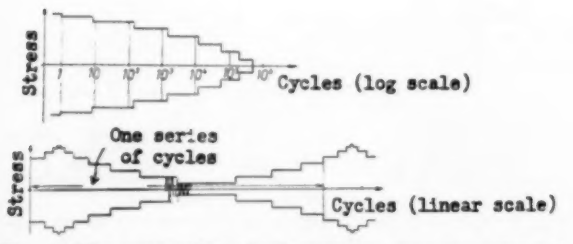


Fig. 4 The conversion of a frequency curve to a stepped curve (upper diagram) and its conversion, in turn, to the variable stress fatigue program (lower diagram), according to Gassner

of specimen. This curve can be used to determine allowable design stress after the application of a safety factor. Although very few tests of this type have been performed, enough fatigue data have accumulated (see References 28 to 31, and the bibliographies in 30 and 31) to allow the "service strength" to be estimated.

ALLOWABLE STRESS AND SAFETY FACTOR

The safety factor we decide to use depends on the accuracy of our knowledge of the stresses to which the structure is to be subjected and on the care with which it is built, as well as on the natural scatter in the measurements of the strength of the materials. If less than 10,000 cycles of stress are expected, the yield strength may be used as the basis for an allowable stress. For 500,000 cycles or more the endurance limit should be used. In the intermediate range we should use the time fatigue strength determined at the desired number of cycles. Suggested values of safety factor are:

(*a*) Against fracture under static stress, at least 1.8, usually 2.5, divided into the tensile strength.

(*b*) Up to 10,000 cycles, safety against yielding. 1.5 to 2.5 divided into the yield strength depending on the severity of the notches. An average value would be 1.7.

(*c*) Up to 500,000 cycles, 1.0 to 1.8 divided into the endurance limit. An average value would be 1.3 to 1.5.

(*d*) Over 500,000 cycles, 1.5 to 3.0 divided into the endurance limit. An average value would be 1.5 to 2.0, but as low as 1.2 has been used.

If we have a frequency curve for service stress but no service fatigue results, the following method[32, 33] is useful. Substitute for the frequency curve, a constant amplitude of stress and a limited number of applications. The rectangle so obtained must have the area under the frequency curve. These amplitudes should be compared with a fatigue test curve to determine the safety factor. For combined bending and torsion stress, ellipses are used.[34, 35]

NOMINAL STRESS AND NOTCH EFFECTS IN WELDED JOINTS

The permissible nominal stress calculated by the above methods does not take into account concentration of stress around notches. The shape factor is only a partial solution, for this factor does not provide the actual peak stress but rather the effect of nonuniform stress distribution on fatigue strength. The permissible nominal stress for welds determined in fatigue tests using the nominal cross-sectional area may be affected by internal as well as external notches. The internal notches are holes, slag inclusions, incomplete fusions, etc. Round holes have least affect on fatigue, while cracks are most dangerous.[36, 37] Holes along the neutral axis of a bend fatigue specimen of a butt weld have no effect on fatigue strength. Likewise shrinkage

holes along the centerline of a spot weld do not lower the fatigue strength in many cases. In general, if the external notches are more severe than the internal, the latter may exert no effect whatever on fatigue strength.

Avoidable external notches are undercut and incomplete root fusion. The reinforcement of a butt weld is an unavoidable notch, as is the unfused zone between the edge of the web and the flange surface of an unbeveled fillet weld or lap weld. In a fillet weld the nominal stress in the plate at the toe of the fillet may be lower than the nominal stress through the throat of the weld. Yet in fatigue test fracture may start at the toe.

RESISTANCE WELDS

Resistance butt, gas pressure[38] and flash[39] welds of good quality have excellent fatigue properties. The reinforcement at the joint generally is so large, even in flash welds, that external notches are unimportant. If the weld is machined below the notches, the full endurance limit of the joint is realized. The following permissible amplitudes of stress are suggested.

(*a*) Unmachined weld $S_{ps} = 0.6$ to $0.8\ S_p$.

(*b*) Machined resistance butt weld $S_{ps} = 0.6$ to $0.8\ S_p$.

(*c*) Machined flash weld $S_{ps} = 0.8$ to $1.0 S_p$.

S_{ps} = normal and shear stress in the weld. S_p = normal stress in the base metal. Lower stresses are permitted in the machined resistance butt weld than in the flash weld, because the former is more likely to contain internal defects.

In spot and seam welds the sharpest notch is the gap between the sheets. Ordinarily the weld nugget is not the location of fatigue failure, which occurs[40-43] instead at the edge of the weld. Safety factors for spot and seam welds cannot be proposed. The arrangement of the spots in a joint has considerable effect on fatigue strength. Arrangements which prevent bending in the plane of the sheets may raise the fatigue strength 20 to 30%. The closer the spots together, the more uniform is the stress distribution, and the higher the fatigue strength.

FUSION WELDS

There are two basic types of fusion welds: the butt weld and the fillet weld, with various intermediate forms. The nominal stress of a butt weld is computed on the minimum cross section at its edge, Fig. 5. The reinforcement is neglected. Fracture under fatigue stress generally occurs at the junction of reinforcement with plate. Excessive reinforcement lowers fatigue strength.

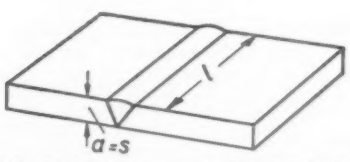


Fig. 5 Calculating the nominal stress in butt welds

For tension and shear: $F = a \times l$. Nominal stress $= P/(a \times l)$. For bending in the plane of the plate: $W_B = la^2/6$. For bending perpendicular to the plane of the plate: $W_B = l^2a/6$. Nominal stress $= M_b/W_b$.

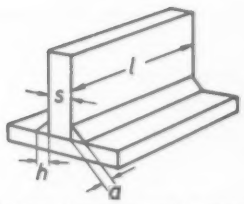


Fig. 6 Calculating the nominal stress in fillet welds

1. Design based on the cross section of the weld.
   (*a*) According the German Standard 4100:
   Tension: $F = \Sigma a \times l$
   Nominal stress $= P/\Sigma a \times l$
   Bending in the plane of the plate:
   $W_b = l[(s + 2a)^3 - s^3]/s + 2a$
   Nominal stress $= M_b/W_b$
   (*b*) Based on leg size
   $F = \Sigma h \times l$
   Nominal stress $= P/\Sigma h \times l$
   $W_b = l[(s + 2h)^3 - s^3]/s + 2h$
   Nominal stress $= M_b/W_b$
2. Design based on cross section at junction of weld with plate.
   Tension: $F = s \times l$
   Nominal stress $= P/s \times l$
   Bending in the plane of the plate
   $W_b = l \times s^2/6$
   Nominal stress $= M_b/W_b$

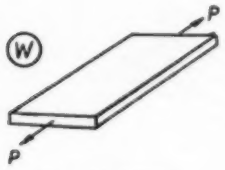
With fillet welds two cross sections must be considered: (*a*) the cross section of the weld, and (*b*) the cross section of the plate at junction with weld. The nominal stress in the cross section of the weld is based on the throat, which in turn is obtained from the inscribed triangle, Fig. 6, as in German Standard 4100. In some countries the leg of the fillet is the basis for computing fillet cross section. Stresses computed on the leg are 0.7 times the stresses computed on the throat. The nominal stress in the plate at the junction with the weld is computed by ordinary formulas without considering stress concentration.

THE FACTOR METHOD FOR PERMISSIBLE STRESSES

Methods of design based on fatigue were developed[44] many years ago for welded plate girder railway bridges. These specification methods introduced two factors to arrive at permissible fatigue stresses from given permissible static loads. The first factor was derived from riveted design and expressed the difference among alternating, pulsating and static stresses. The second factor evaluated the effect of the shape of the joint on fatigue strength. The two factors may be used in two ways. Either a fictitious stress may be computed from the estimated nominal stress, the fictitious[44] stress being compared with the permissible static load. Or inversely from the permissible load a permissible nominal stress[45] may be computed with the aid of the factors, which is compared with the actual stress. If the two factors are γ and α,

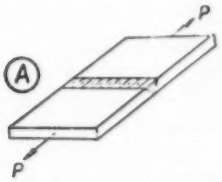
Method 1: The ficticious stress is $S = (\gamma/\alpha) \times S_n \leqq S_{ps}$.

Table 2—Permissible Stresses for Welded Mild Steel Railway Bridges



Unwelded Plate

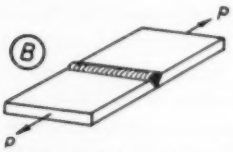
W: If maximum stress is tensile.
$\overline{W}$: If maximum stress is compressive.



High-Quality Butt Weld

Single and double-bevel butt welds transverse to the direction of stress. Machined flush with the plate and free from notches. The root is reverse welded, and the joint is radiographed.

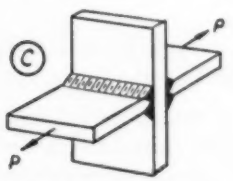
A: When the maximum stress is tensile.
$\overline{A}$: When the maximum stress is compressive.



Butt Weld, Standard Quality

Single and double-bevel butt welds transverse to the direction of stress. The root is reverse welded and the joint is radiographed.

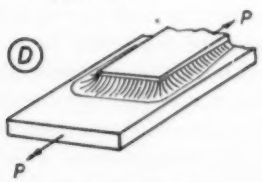
B: When the maximum stress is tensile.
$\overline{B}$: When the maximum stress is compressive.



Beveled Fillet Weld

Unmachined, transverse to the direction of load.

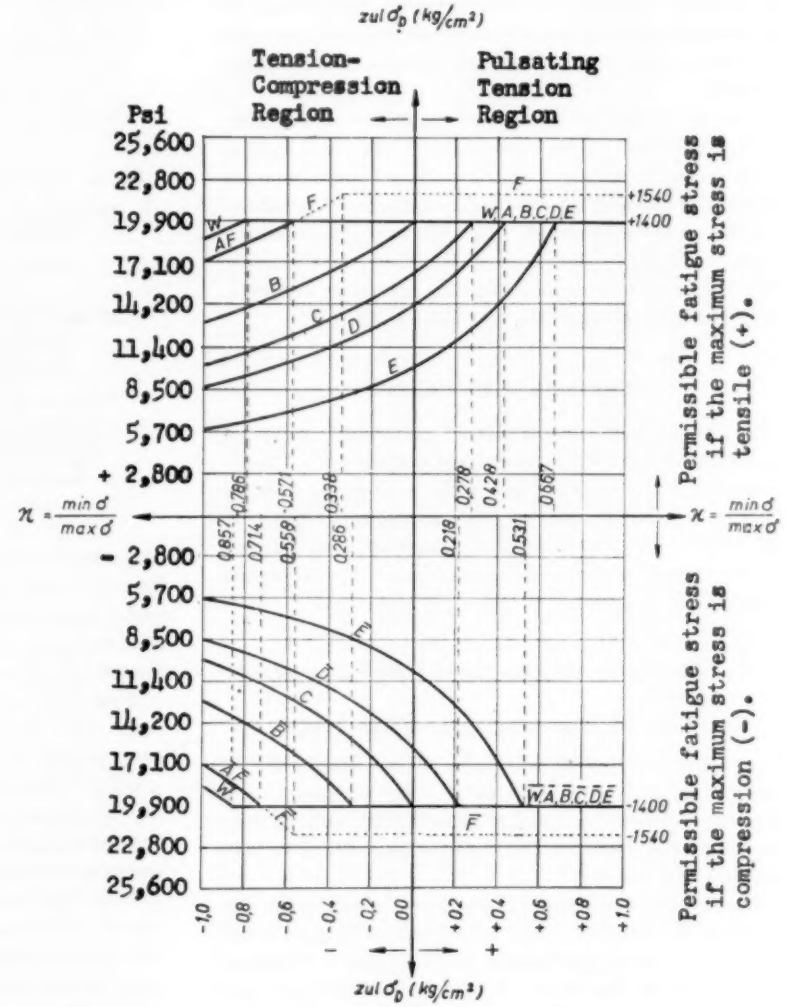
C: When the maximum stress is tensile.
$\overline{C}$: When the maximum stress is compressive.



Machined Lap Weld

Such as for a cover plate with flared fillet.

D: When the maximum stress is tensile.
$\overline{D}$: When the maximum stress is compressive.

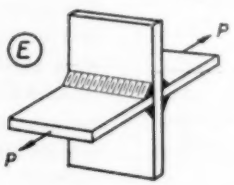


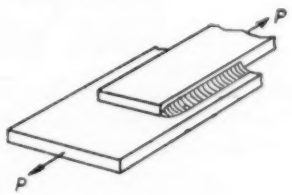
Permissible stresses according to Section 4 of the 1951 edition of the *German Railways Specifications for Welded Plate Girder Railway Bridges.*[44a]

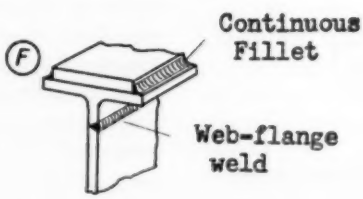
χ = ratio of minimum stress to maximum stress.
$zul\ \sigma_d$ = permissible fatigue stress.

Unmachined Fillet. Ordinary end and side fillets.

E: When the maximum stress is tensile.
$\overline{E}$: When the maximum stress is compressive.







Unmachined Web-to-Flange Weld

Continuous butt, *K*, or fillet weld joining web plates to flanges.

F: When the maximum stress is tensile.
$\overline{F}$: When the maximum stress is compressive.

Lines *F* and $\overline{F}$ represent the permissible principal stress.

Method 2. The permissible nominal fatigue stress is $S_{pf} = \alpha/\gamma \times S_{ps}$; $S_n \leqq S_{pf}$.

where

S_n = nominal stress computed from loads or moments and the dimensions of the cross section.
S_{ps} = permissible stress for statically loaded parts of the material.
S_{pf} = permissible nominal stress in fatigue.

The γ factor is read from fatigue diagrams or from the diagram of permissible loads for unwelded or riveted structures, Fig. 7. If the structure is subjected to the varying load shown in Fig. 8, this type of loading is expressed by the ratio of the bending moments: M_{min}/M_{max}. The ratio is negative in this case, but is positive for pulsating loads. In Fig. 7 the permissible upper stress corresponding to the ratio $S_u/S_o = M_{min}/M_{max}$ is S_{op}. The γ factor is the ratio of the permissible static load to S_{op}, and therefore depends on the shape of the diagram of permissible fatigue loads. In the specifications the γ factor is listed in Tables, and has different values in different countries. Different countries also use different formulas for calculating γ. The German[44] formula is $\gamma = C_1 - C_2 \times M_{min}/M_{max}$ where C_1 and C_2 are constants depending on the material and the frequency of loading. The Austrian[45] formula is $1/\gamma = K_1(1 + K_2 M_{min}/M_{max})$ where K_1 and K_2 are constants varying with different materials.

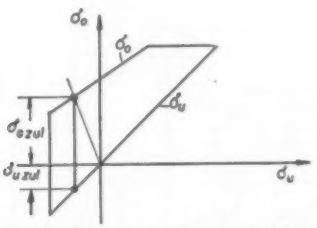


Fig. 7 Schematic diagram of permissible fatigue stress
σ_{ozul} = upper permissible stress; σ_{uzul} = lower permissible stress.

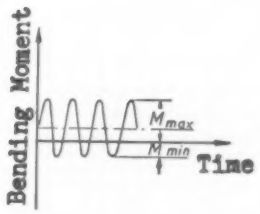


Fig. 8 Assumed example of reversed bend stress

The α factor expresses the difference in fatigue strength among different types of joint. Since the diagrams of permissible stress derived from fatigue tests on different types of joint (fillet, butt, etc.) are not similar, Fig. 9, the α factor is not a constant but varies with the ratio of minimum to maximum load (for example, M_{min}/M_{max}).

Nowadays in Germany the α and γ factors have been abandoned. Permissible nominal stresses are obtained instead from tables [44a] or diagrams for different values of ratio of lower to upper stress, Table 2. These permissible nominal stresses are obtained from fatigue strengths by dividing by the required safety factor.

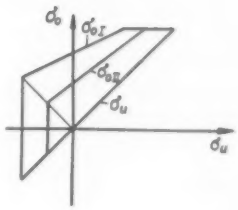


Fig. 9 Comparison of schematic diagram of permissible fatigue stresses with two different notch severities

For approximate fatigue calculations it is often possible to assume that the amplitude of stress does not change much as the lower stress is raised. In this event the permissible amplitude of stress can be determined from the amplitude of stress measured in the fatigue test and the necessary safety factor. This method is used particularly for fillet welds.

Machine designers have devised a system[9] of factors for designing welded joints in fatigue, which has been reduced to tabular form.[32, 33] The system is based on experimental fatigue results and factors for type of joint, for disturbances to uniform stress flow occasioned by design, for increased initial stress and shrinkage stress, and for the expected number of cycles of stress, Table 3.

BUTT WELDS

There are three starting points for fatigue fractures in butt welds: internal defects, poorly welded root and the junction of weld with plate. The pulsating tension fatigue strength of machined specimens of mild steels in one series of tests [36] was 45,500 psi, which was lowered to 31,300 psi if the mill scale was not removed. Occasional small porosity in the weld lowered the fatigue strength to 28,400 psi. Large slag inclusions or incompletely fused root lowered the fatigue strength to 18,500 psi. Still lower values were reported for abnormally large defects.

Aside from avoidable defects, an unavoidable defect, such as the incompletely fused root of a *V* or *U* butt welded from only one side in mild steel, may lower the fatigue strength 50 to 60% below the plate even with good welding. If the reinforcement is not machined from a butt joint welded from both sides, the fatigue strength is about 70% of unwelded plate. When the reinforcement is machined off, or the junction of plate to weld is ground, the fatigue strength of a butt joint welded from both sides is 90% of unwelded plate.

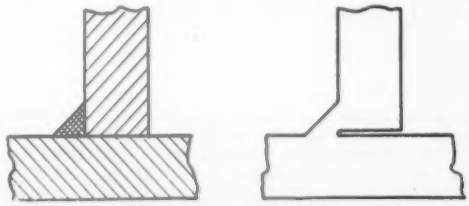


Fig. 10 Root notch in a one-sided fillet. The schematic fusion diagram (right) portrays the notch particularly well

The corresponding percentages for high tensile steel are 80, 60 and 80%, respectively. Table 4 lists permissible fatigue values for butt joints in pulsating tension, tension-compression and bend fatigue. For shear or torsion these values are multiplied by 0.75.

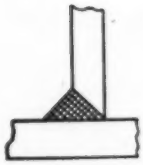


Fig. 11 Fillet weld with beveled plate welded from one side

FILLET WELDS

The stress concentration in fillet welds made from one side in unbeveled plates, Fig. 10, is so high[46] that the permissible tension-compression fatigue stress is only ±1400 psi. If the web plate is beveled, Fig. 11, the permissible tension-compression fatigue stress is higher, ±4300 to ±5000 psi. Even if the joint is welded from both sides, Fig. 12, which eliminates ec-

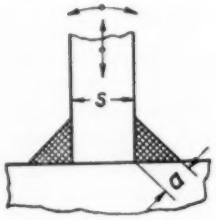
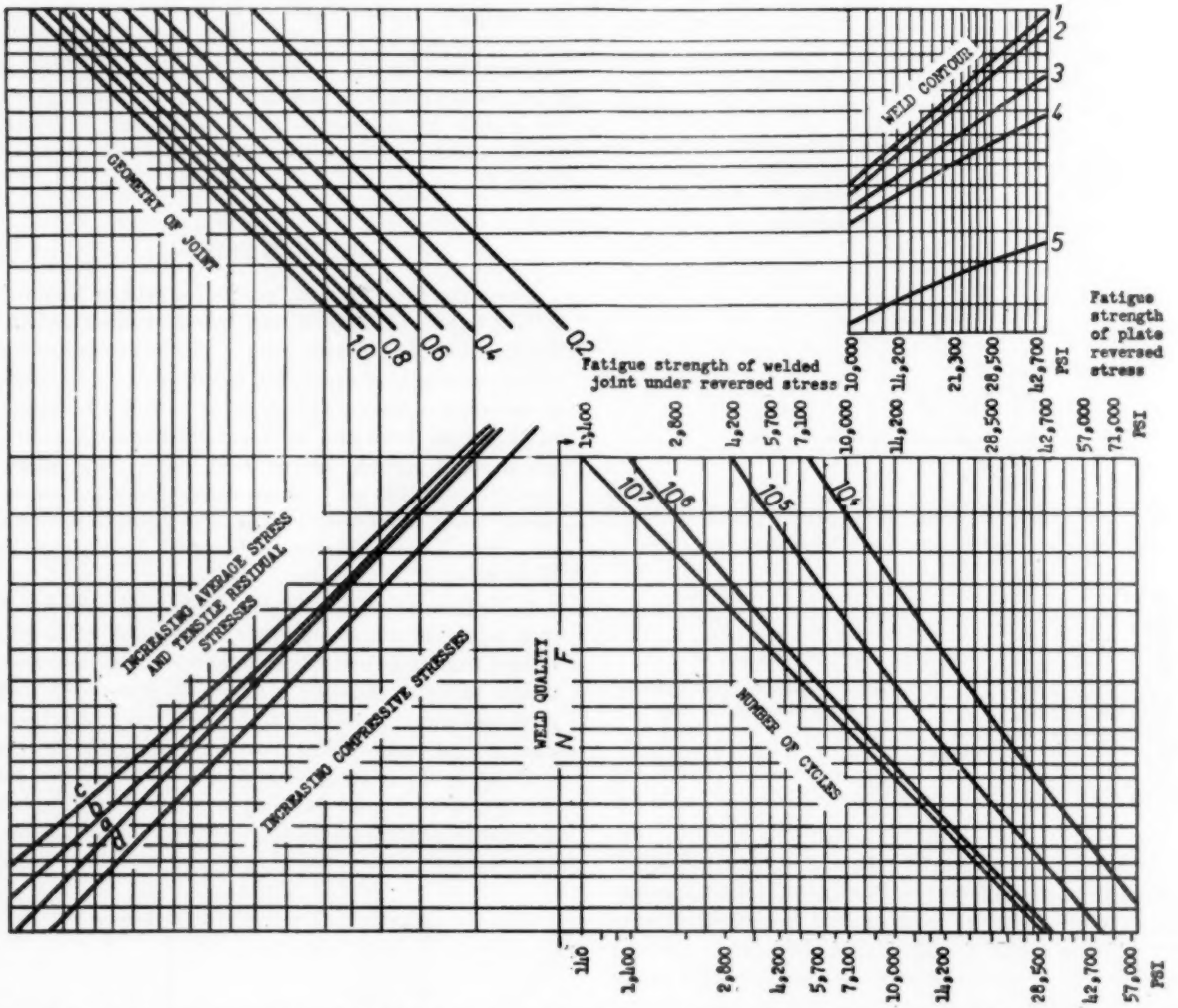


Fig. 12 Fillet-joint welded from both sides

Table 3—Tables and Nomogram for Calculating the Fatigue Strength of Welded Joints[33]

Table 3A: Calculating the Endurance Limit and Fatigue Strength at a Limited Number of Cycles for Welded Joints



Begin at the upper right quadrant. Locate on the horizontal axis the reversed stress fatigue strength of unwelded plate derived from Table 3C. Proceed vertically to the line applying to the weld contour derived from Table 3B. Proceed horizontally to the upper left quadrant to the proper line for geometry of joint using the geometry factor b_3 from Fig. 3D. From here proceed vertically down to the lower left quadrant to the proper line for average and shrinkage stresses derived from Table 3E. Now proceed horizontally to the lower right quadrant to the proper line for the expected number of cycles of stress. We can now proceed vertically to either the upper or lower horizontal axis of the lower right quadrant. Both axes show the fatigue strength of the welded joint at the expected number of cycles. The upper axis relates to high quality welds (quality *F*), the lower to low quality welds (quality *N*).

Table 3B: Rules for Selecting the b_1 Factor for Different Weld Contours

Type of weld	*Cross section*	*Load*	*Direction of load with respect to direction of weld*	*Reference line*
Butt welds:				
Double bevel and single bevel welds with root reverse welded	Machined junction	Any	Any	1
	Junction not machined	Any	Transverse	3
			Longitudinal	2
Single bevel welds without reverse welding of root	Weld	Any	Transverse	4
			Longitudinal	3
	Junction not machined	Any	Transverse	3
			Longitudinal	2
Double bevel butt weld with incomplete root fusion	Weld	Tension-compression	Transverse	5
		Bending	Longitudinal	4
		Shear	Any	4
Fillet joint welded on both sides*	Weld	Tension-compression	...	5
		Bending		
		Shear	...	4
	Junction not machined	Any	...	3 for concave weld 4 for flat contour
	Machined junction	Any	...	2
Fillet joint with beveled web welded on both sides	Machined junction	Any	...	2
	Junction not machined	Any	...	3 for concave weld 4 for flat contour

* The same reference lines should be used for fillets welded on one side. However on account of unfavorable stress concentration, the geometry factor b_3 for the fillet welded on one side should be multiplied by 0.5 to 0.7.

Table 3C: Average Reversed Stress Endurance Limits of Different Steels

Tensile strength, psi	*Reversed stress fatigue strength, psi*		
	Tension-compression	*Bending*	*Torsion (shear)*
53,000	±18,500	±22,800	±15,600
74,000	±25,600	±29,900	±19,900
100,000–114,000	±28,500	±32,700	±22,800

Table 3D: Selection of the Geometry Factor b_3

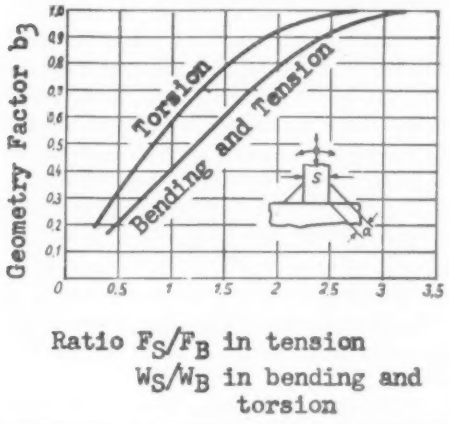


Table 3E: Selection of Reference Lines for Higher Average Stresses and Shrinkage Stresses

Average stresses	*Reference line*
Zero (pure reversed stress)	*a*
Not zero (tension or shear)	*b*
Shrinkage stresses	
Low natural shrinkage stresses	*a*
Higher natural shrinkage stresses and average external restraint	*b*
Very high natural shrinkage stresses and high external restraint	*c*
Compressive shrinkage stresses at notches	*d*

Combinations of shrinkage stresses and high average stress shift the reference line still higher.

Table 4—Permissible Fatigue Stresses (Psi) for Butt Welds

	Tension-compression fatigue, $\pm S_{ps}$		*Pulsating tension fatigue, S_{pp}*		*Maximum upper tensile stress with high tensile prestress, S_{po}*	
	Mild steel	*Low-alloy steel*	*Mild steel*	*Low-alloy steel*	*Mild steel*	*Low-alloy steel*
Unwelded plate	±15,700	±15,700	20,000	24,200	20,000	30,000
Reverse welded joint, machined	±12,800	±12,800	15,700	17,100	15,700	24,200
Reverse welded joint, not machined	±10,000	±10,000	14,200	15,700	15,700	24,200
Joint without reverse welded root	±7,100	±7 00	11,400	11,400	15,700	24,200

The mild steel has a minimum static tensile strength of 53,000 psi. The low-alloy steel has a minimum static tensile strength of 74,000 psi.

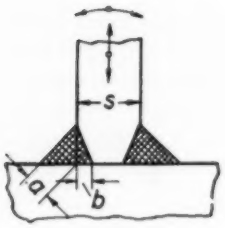


Fig. 13 Fillet joint with partly beveled web welded from both sides but without complete penetration

centric loading, the permissible stress is only ±2800 to ±3600 psi. With beveled web plates, Fig. 13, the range is ±4300 to ±5000 psi. If beveling is carried to the point where the fillets overlap, the critical section is at the junction of weld with web. At the junction any slight defect or undercut acts as a notch. The smaller the weld compared with the plate, the greater is the concentration of stress, Fig. 14 and Table 5. The most favorable throat thickness for fillets of the type shown in Fig. 14 in bending is 0.5 times the web thickness, for then fatigue failure is certain to start at the junction of weld with plate. Conditions are different under tensile stress. To ensure fatigue failure at the junction of weld with plate the throat of the weld would have to be too large to be practical. Therefore beveled web plates are used in tension, and the gap between the plates is fused completely. Under these conditions the junction of weld with web is the dangerous section, and the fatigue strength is practically the same as for a butt weld.

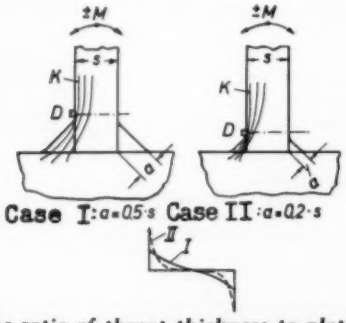
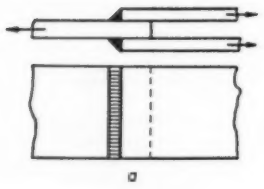


Fig. 14 The ratio of throat thickness to plate thickness affects the distribution of stress in the cross section of junction of weld with plate in a fillet-joint welded from both sides. Case I (left) a = 0.5s; Case II (right) a = 0.2s



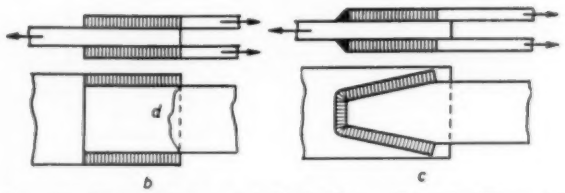


Fig. 15 Strap joints: (a) End fillet; (b) side fillet; (c) inclined fillet; (d) location of fatigue failure

The use of splice plates, Fig. 15, is carried over from riveted design. Fatigue tests[47–49] have shown that welded straps have low fatigue strength. The permissible reversed stress fatigue strength is ±1400 to ±2800 psi, which is a little higher than for the fillet in Fig. 12 because the gap between the plates lies in the direction of stress. The fatigue strength of the junction between plate and weld varies with its inclination from ±1400 to ±4200 psi. The lower value applies to Fig. 15(*b*), the higher to Fig. 15(*c*).

WELDS IN STRUCTURAL PARTS

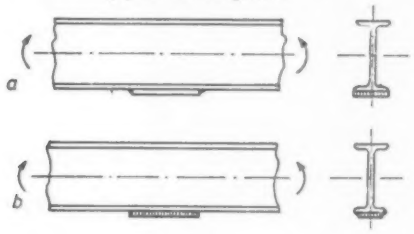
The weld attaching a secondary member to a stressed member has no more effect than the junction between a butt weld and a plate.[50, 51] If, however, the weld transfers stress from the one member to the other, as in reinforcing plates on girders,[52–54] conditions are different. A short plate welded to the tension side of a beam, Fig. 16(*a*), with end or side fillets reduces the fatigue strength at least 50%. This reduction applies to the beginning and end of the welds. If the cover plate is extended into the low-stress zones of the beam and side fillets are used, Fig. 17(*a*), there is little notch effect because practically only shear stress is transferred

Table 5—Reversed Stress Fatigue Strength and Permissible Amplitude of Stress for Fillet-Welded Joints in Tension and Bending as a Function of Weld Size

Throat of fillet, a in Fig. 14	*Plate Thickness, in.*	*Reversed stress fatigue strength, psi*		*Permissible amplitude of stress, ±psi*	
		Unmachined	*Smoothly machined junction of weld with plate*	*Unmachined*	*Smoothly machined junction of weld with plate*
0.2 *S*	3/16	8,500		5,700	
0.2 *S*	3/8	6,400		4,300	
0.2 *S*	9/16	5,700	Note A	3,600	Note A
0.3 *S*	3/16	12,800		8,500	
0.3 *S*	3/8	10,000		6,400	
0.3 *S*	9/16	9,300		5,700	
0.4 *S*	3/16	15,600	21,300–25,600	10,000	14,200
0.4 *S*	3/8	12,800	18,500–22,700	8,500	12,800
0.4 *S*	9/16	11,400	17,100–21,300	7,100	11,400

NOTE A: Machining is useless because of the severity of the root notch.

Fig. 16 Beams with short cover plates welded to the tension flange. See Table 5 for results. (a) With end fillets; (b) with side fillets



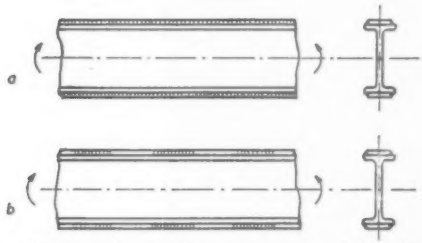


Fig. 17 Beams with continuous flange reinforcing plates. See Table 5 for results. (a) With continuous fillets; (b) with intermittent fillets

from beam to plate. The nominal stress may amount to 55 to 75% of the unwelded beam and the weld has not much greater effect than a butt weld. If intermittent fillets are used the nominal stress falls to 30 to 50%, because the end of each short weld is a notch. To estimate whether the "reinforcement" has really strengthened the beam the nominal stress is less important than the bending moment, Table 6. Despite the lowering of the nominal stress, the resisting moment of the beam may be raised sufficiently by the reinforcement to raise the over-all fatigue value. With intermittent fillets the notch effect is so great that, no matter how great the reinforcement and accompanying greater stiffness, the reinforced beam cannot have greater resistance to fatigue loads than the unreinforced beam.

Table 6—Comparison of Reinforced Beams

Type	*Description*	*I and W, %**	*Endurance limit, %*	*Bending moment at endurance limit, %*
...	Unreinforced beam	100	100	100
Fig. 16(*a*)	Short cover plate with end fillets in the tension flange	100	40–50	40–50
Fig. 16(*b*)	Short cover plate with side fillets in the tension flange	100	40–50	40–50
Fig. 17(*a*)	Continuous cover plate with continuous fillets	150–200	55–75	90–150
Fig. 17(*b*)	Continuous cover plate with intermittent fillets	150–200	30–50	50–90

* I = moment of inertia in bending; W = bending moment that can be sustained.

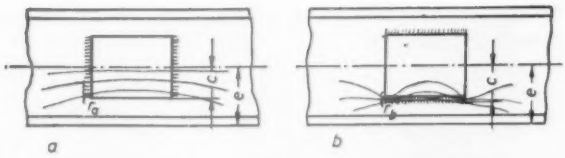


Fig. 18 Beams with reinforcing plates welded to the web. (a) With end fillets; (b) with side fillets; r = location of fatigue failure

If the web is reinforced, the fatigue strength of the beam may or may not be decreased, depending upon whether or not the notch effect at the weld is smaller than the ratio of nominal stresses at the weld and at the extreme fiber. This is the ratio between the distance from weld to neutral axis divided by the distance from extreme fiber to neutral axis. In Fig. 18 the fatigue strength at the end of an end-fillet-welded web reinforcement averages 45% of the fatigue strength of the unwelded beam. The corresponding figure for a side fillet welded reinforcement is 35%, owing to the high stress concentration at the side fillets. The nominal fatigue strength in both situations is:

Reinforcement with end fillets $S'_f = 0.45\ (e/c)\ S_f$.
Reinforcement with side fillets $S'_f = 0.35\ (e/c)\ S_f$.

where S_f is the fatigue strength of the unreinforced beam. If the calculated nominal stress is higher than the fatigue strength of the unreinforced beam, the weld does not affect the fatigue strength, which is the case if c/e is less than 0.45 or 0.35 for end and side fillets, respectively.

EXAMPLE 1. Fillet-welded joints subjected to tension-compression, reversed bending or reversed torsional loads.

1. Cross section at the junction of weld with web. If a fillet weld of throat a is used to weld a plate or round bar of thickness s (or diameter s) to a plate or flange the distribution of stress depends on the ratio a/s. We calculate:

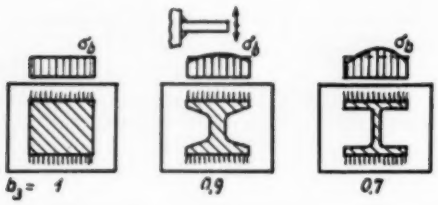
For tension-compression loading, the ratio F_S/F_B.
For bending, the ratio W_{bS}/W_{bB}.
For torsion, the ratio W_{dS}/W_{dB}.

We used these ratios to derive the geometry factor from Fig.D.

F_S = cross-sectional area of the weld = $a \times l$.
F_B = area of base metal at weld-base metal junction = $s \times l$ (or $\pi s^2/4$).
W_{bS} = resisting moment in bending of the weld according to German Standard 4100.
W_{bB} = resisting moment in bending of the base metal.
W_{dS} = resisting moment in torsion of the weld = $(s \pm 0.7a)^2 \pi a/2$ for circumferential fillet welds on shafts.
W_{dB} = resisting moment in torsion of the base metal.

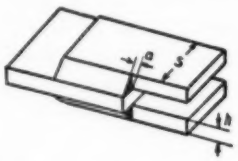
2. Cross section of the weld. The ıetry factor b_3 always is unity for the cross sectioı the weld. because the effect of the geometry of the structure itself is slight compared with the very sharp root notch which has been taken into account under "Contour of Weld," Table 3B.

EXAMPLE 2. The connections shown below loaded in reversed bending.



On account of the absence of the stiffening action of the web, the stress distribution is not uniform over the length of welds connecting structural shapes. The fatigue strength is decreased in the ratio of average stress to maximum stress. If $W_S/W_B \geqq 3$ the given geometry factors apply. For $W_S/W_{Be} < 3$ these factors for the junction must be multiplied by the corresponding factors of Section 1 of Example 1.

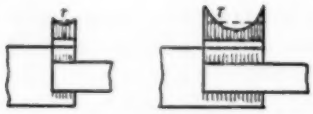
EXAMPLE 3. Side-fillet-welded strap joints.



1. Cross section of weld. On account of the peak stresses at the end of the welds the geometry factor b_3 always is less than 1. The factor is larger for short welds than for long welds.

Shear stress on the cross section of the weld

Short weld	Long weld
$b_3 = 0.8$	$b_3 = 0.5$



2. Cross section at the junction of weld with plate. The junction cross section is treated as a fillet-welded joint loaded in reversed tension-compression. The geometry factor lies between 0.3 and 0.6 depending on the sharpness with which the lines of stress must bend.

References

1. Hempel, M., "Fatigue Testing and the Behavior of Materials in Fatigue. Part 1. Fatigue Tests to Serve as a Basis for Design," *Z. VDI*, **94** (25), 809–815 (1952).
2. Schaefer, W., "The Effect of Notches Under Static Tensile Loads," *Konstruktion*, **4** (3), 71–77 (1952).
3. Kirsch, A., "Notch Tensile Tests on Heat Treated Steels," *Archiv. Eisenhüttenw.*, **22** (11–12), 395–400 (1951).
4. Buchmann, W., "The Notch Sensitivity of Materials," *Forsch. Ing. Wes.*, **5**, 36–48 (1934).
5. Siebel, E., and Meuth, H. O., "The Effect on Notches in Fatigue," *Z. VDI*, **91** (13), 319–323 (1949).
6. Schwaigerer, E., "Material Factors and Safety in Design," *Konstruktion*, **3** (8), 233–239; (11), 350 (1951).
7. Petersen, C., "The Geometry Factor in Structures," *Z. VDI*, **94** 977–982 (1952).
8. Thum, A., and Bautz, W., "The Shape Strength," *Schweiz. Bauzeitung*, **106**, 25–30 (1935).
9. Bobek, K., "Designing Welded Joints in Fatigue," *Elektroschweissung*, **7**, 41–45 (1936).
10. Schimpke, P., Horn, H., and Hänchen, R., "Design and Specifications for Welded Structures," *Practical Welding Handbook*, Vol. III, Springer-Verlag, Berlin (1952).
11. Hempel, M., "Fatigue Testing and the Behavior of Materials in Fatigue. Part II. Fatigue Tests with Stepwise Changes in Load," *Z. VDI*, **94** (26), 882–887 (1952).
12. French, H. J., "Fatigue and the Hardening of Steels," *Trans. ASST*, **21**, 899–946 (1933).
13. Müller-Stock, H., Gerold, E., and Schuls, E. H., "The Effect of Preliminary Cycles of Reversed Stress on the Reversed Bend Fatigue Strength of Mild Steel at Various Numbers of Cycles of Stress," *Archiv. Eisenhüttenw.*, **12**, 141–148 (1938–39).
14. Thum, A., and Erker, A., "Fatigue Strength at Various Numbers of Cycles of Stress and the Effect of a Single High Overload," *Z. VDI*, **86**, 171–174 (1942).
15. Drosd, A., Gerold, E., and Schuls, E. H., "The Effect of Reversed and Impact Overloads on the Life of Steel in Reversed Bending Fatigue," *Archiv. Eisenhüttenw.*, **21** (5/6), 181 (1950).
16. Gassner, E., "Repeated Load Tests in Aircraft Construction," *Luftwissen*, **6**, 61–64 (1939).
17. Teichmann, A., "Fundamentals of Service Strength Testing," *Jahrbuch Deutsch. Luftfahrtfschg.*, **I**, 467–471 (1941).
18. Gassner, E., "Effect of Cycles of Load Similar to Service on Aircraft Structures," *Ibid.*, **I**, 472–483 (1941).
19. Gassner, E., "Load Measurements and Service Strength Tests on Aircraft Structures," *Autom-techn. Z.*, **53**, 286–287 (1951).
20. Thum, A., and Svenson, O., "Contact Extensometer for Measuring Service Loads," *Z. VDI*, **88**, 153 (1944).
21. Merz, L., "Resistance Strain Gages," ATM-Blatt V91122-11 and -12 (July and August 1950).
22. Fink, K., "Extensometer Strips," *Z. VDI*, **92**, 89 (1950).
23. Erker, A., and Svenson, O., "Measuring Fatigue Loads," ATM-Blatt V131-1 (March 1951).
24. Koch, J. J., Boiten, R. G., Biermasz, A. L., Roszbach, G. P., and van Sauten, G. W., "Strain Gage Technique," *Philips' techn. Bibliothek*, Hamburg (1951).
25. Schuls, R., "Dynamic Induction Strain Gage," ETZ 72 (6), 177–179 (1951).
26. Krisement, O., "Practical Stress Analysis with Extensometers," *Archiv. Eisenhüttenw.*, **23** (3/4), 157–161 (1952).
27. Lambie, J. B., "The Counting Strain Gage," *Engineering*, **174**, 168–169 (1952).
28. Graf, O., "Fatigue Strength of Steels with Mill Scale, with and Without Holes, Riveted Joints, and Welded Joints," *VDI*, Verlag, Berlin (1931).
29. Graf, O., "Fatigue Tests on Welded Joints," *Ibid.* (1935).
30. Spraragen, W., and Claussen, G. E., "Review of Literature on Fatigue," THE WELDING JOURNAL, **16** (1), Research Suppl., 1–44 (1937).
31. Erker, A., and Thum, A., "Shape Strength of Welded Structures," *Werkstoffe und Schweissung*, Akademie Verlag, Berlin, 896–993 (1951).
32. Thum, A., and Erker, A., "Welding in Machinery Construction. Part I. Strength and Design of Welded Joints," *VDI*, Verlag, Berlin (1942).
33. Thum, A., and Erker, A., "Shape Strength of Welded Joints," *Mitt. Mat. Prüf. Anst. Darmstadt, H. 19. VDI*, Verlag, Berlin (1942).
34. Gough, H. J., and Pollard, H. V., "The Effect of Shape of Specimen on the Resistance of Metals to Fatigue," *Proc. Instn. Mech. Engrs.*, **132**, 549–573 (1936).
35. Thum, A., and Kirmser, W., "The Production of Superimposed Reversed Stresses and Their Effect on Fatigue Stress and Stress Concentration in Shafts with Transverse Holes," *VDI-Forsch.*, Heft No. 419, Berlin (1943).
36. Hempel, M., and Möller, H., "The Effect of Defects in Welds in Mild Steel on Their Pulsating Tension Fatigue Strength," *Archiv. Eisenhüttenw.*, **20** (11/12), 375 (1949).
37. Green, G. J., and Marlin, D. H., "Stress Concentration Problems in Welded Construction," THE WELDING JOURNAL, **30** (7), 607–617 (1951).
38. Renner, O., and Wolff, L., "Oxyacetylene Pressure Welding," *Schweissen u. Schneiden*, **2**, 283–293 (1950).
39. Kilger, H., *Production and Quality of Flash Welded Joints*, F. Vieweg, Braunschweig (1936).
40. Hauk, V., "Static and Fatigue Strength of Spot Welds in High Tensile Steel," *Archiv. Eisenhüttenw.*, **20** (1/2), 41–51 (1949).
41. Schuls, G., "The Static and Fatigue Strength of Spot Welds," Diss. T. H. Darmstadt.
42. Kihara, H., "Fatigue Strength of Spot Welded Light Alloy Joints," THE WELDING JOURNAL, **30**, Research Suppl., 529-s to 526-s (1951).
43. Holt, M., and Hartmann, E. C., "Fatigue Tests on Aluminum Alloy Spot Welded Joints," *Ibid.*, **31** (4), Research Suppl., 183-s to 187-s (1952).
44. "Specifications for Welded Plate Girder Railway Bridges," Berlin (1935).
44a. 1951 Edition of Section 4: *Design of Welded Railway Bridges.*
45. Melhardt, H., "The Austrian Standard B 4300/3, Welded Steel Structures," *Schweisstechnik* (2/3) (1952).
46. Dienst, H., "Strength of Fillet Welds of Different Contours Made from One Side of the Joint," *Schweissen und Schneiden*, 3 (4), 112–114 (1951).
47. Bierett, G., and Grüning, G., "Stress Distribution in End Fillet Welds," *Stahlbau*, **6**, 169–173 (1933).
48. Schick, W., "Effect of Shape on the Fatigue of Welds," *Techn. Mitt. Krupp*, **2**, 43–62 (1934).
49. Graf, O., "The Effect of the Shape of the Ends of Welded Cover Plates on Tension Flanges of Beams," *Ber. dtsch. Ausech. Stahlbau, Ausg. B, H. 8*, Springer, Berlin (1937).
50. DeLeiris, H., "Fatigue Tests on Welds," *Soudure Techniques Connexes*, **5**, 53–65 (1951).
51. Dutilleul, H., "Fatigue Tests on Arc Welded Joints," *Ibid.*, **5**, 97–108 (1951).
52. Graf, O., "Fatigue Tests on Cover Plates Welded to Tension Members and Beams," *Z. VDI*, **82**, 158 (1938).
53. Erker, A., "The Effect of Holes, Rivets, and Welds on the Fatigue Strength of Structures," *Dtsch. Kraftfahrtfschg., H. 35, VDI*-Verlag, Berlin (1939).
54. "Fatigue Tests of Beams in Flexure," THE WELDING JOURNAL, 30 (3), Research Suppl., 105-s to 115-s (1951).

ANACONDA
WELDING RODS

PROUD MANUFACTURER. Elmer Rulf points to weld made with ANACONDA-997 (Low Fuming) Rod on side piece of generator frame made of steel tubing. None of the 2,880,000 welds made on these frames has ever pulled apart.

2,880,000 welds

. . . without one customer complaint

"IN four years, we've turned out 96,000 generator frames," says Elmer Rulf, President, Eldon Mfg. & Engr. Co., Inc., Milwaukee, Wisconsin. "Each steel-tube frame requires 30 braze connections. On this job alone, we figure we've made 2,880,000 welds – all with ANACONDA-997 (Low Fuming) Bronze Welding Rods. We haven't heard a single complaint.

ELDON'S WELDER, JACK CORBETT, uses ANACONDA-997 (Low Fuming) Rod to make 1 of 30 braze connections the frame needs. Eldon also brazes lawn-mower and chain saw handles, flexible tube for air ducts.

"ANACONDA-997 Bronze Rods give strong, sound welds every time. They have a low melting point, tin easily and flow freely. Work needs less preheating, too. We do the job faster and at lower cost—with no danger of warping or cracking. Our welds are cleaner, better looking and the welds are far easier to finish."

Badger Welding Distributors, who supply Eldon with all their ANACONDA Rods, hear many such success stories. Your distributor can tell you how ANACONDA Rods can boost your own production efficiency. ANACONDA Welding Rods for many types of repair and production jobs are available from distributors throughout the United States and Canada. For latest tips on welding, write for Booklet B-13 to: *The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.* 53164

braze or weld with confidence—

ANACONDA®
welding rods

NOW! A WATER-COOLED HELIWELD HOLDER

—THE AIRCO® H12A

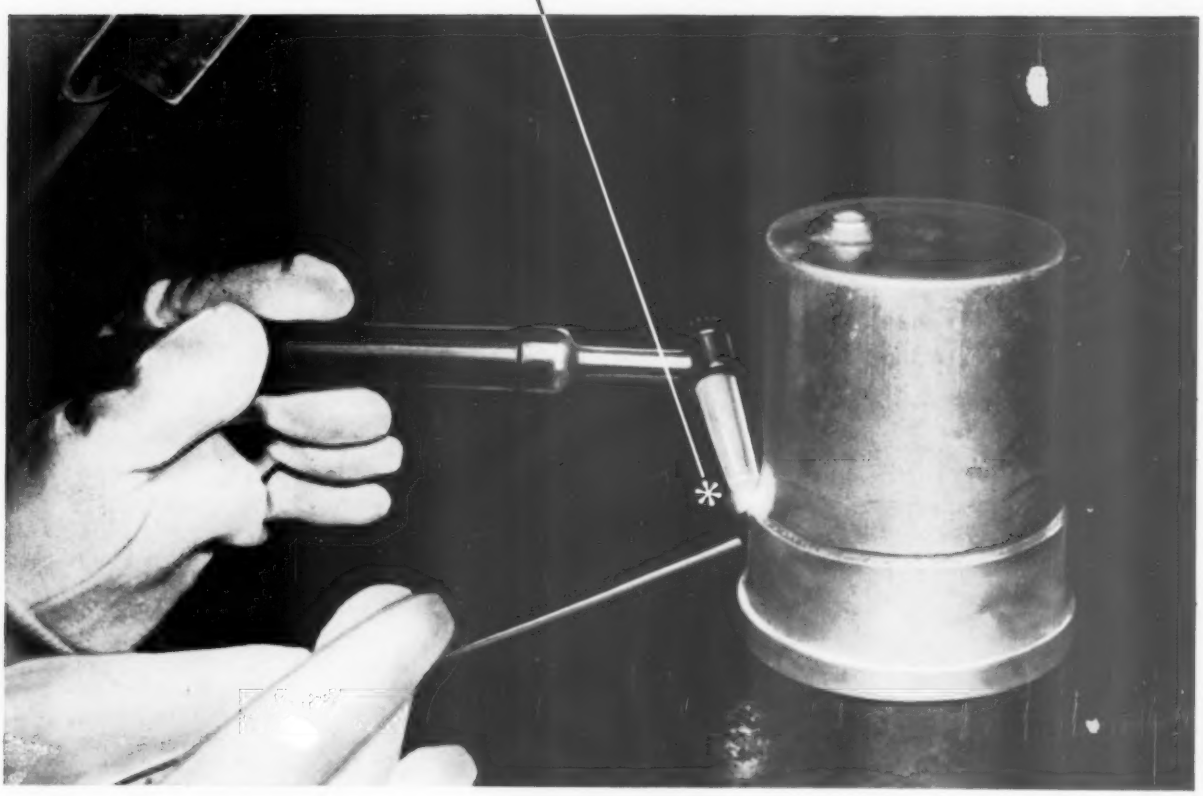
for only

$58.30

This brand-new Airco Heliweld holder gives you quality welds in thin-gauge aluminum, stainless steel, magnesium and copper alloys with ease and convenience . . . and at a highly attractive price. The H12A combines light weight with water cooling. Weighs only four ounces and is 7½ inches long. Continuous duty rating of 125 amps AC or DC. It's the perfect answer to fatiguing long-run jobs, and to making welds in tight corners, where the water cooling keeps it from overheating. Like other Airco manual Heliweld holders, the H12A has gastight "0"-ring seals in the nozzle and cap assembly and takes a full selection of collets and ceramic nozzles . . . no arc-shorting in confined areas!

The $58.30 price includes holder, collet, nozzle, cap assembly and cable assemblies . . . with no sacrifice in usual high Airco quality.

For complete information on this and other Airco Heliweld equipment, see your Airco dealer, or write for Catalog 2300, "Airco Heliwelding Equipment."



AIR REDUCTION

60 East 42nd Street • New York 17, N. Y.

at the frontiers of progress you'll find...

AN AIR REDUCTION PRODUCT

Divisions of Air Reduction Company, Incorporated, with offices and dealers in most principal cities

Air Reduction Sales Company
Air Reduction Magnolia Company
Air Reduction Pacific Company

Represented Internationally by
Airco Company International

Foreign Subsidiaries: Air Reduction Canada Limited, Cuban Air Products Corporation